

THE APPLICATION OF THE MODIFIED CRUDE SETTLEABLE DUST APPROACH AS A VIABLE ASBESTOS MINERAL TEST METHOD

By

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Dedication

The author would like to dedicate this thesis to her father, Mr Pheaga Gad Kwata, mother, Mrs Makwena Hellen Kwata, brother, Sello Seanego Samuel Kwata and her nephew, Pheaga Gad the third Kwata. Also, the author would like to dedicate the thesis to all her relatives including her grandmother, Mrs Ngwakana Maria Kwata and late grandparents, Mr Taeshi Philemon Rapudi, Mrs Mmathopa Sofiah Rapudi and Mr Seanego Samuel Kwata.

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Synopsis

Soil and other geological materials found on the crust of the Earth are known to be rich in naturally occurring silicate minerals. Asbestos is one of the fibrous silicate minerals that was mined predominantly in some regions of Limpopo, Mpumalanga and Northern Cape provinces in South Africa. Despite the cessation of asbestos mining due to associated human health effects in 2002, there is still a concern about possible environmental exposure to asbestos fibres. A single asbestos fibre is made of millions of microscopic needle-like fibrils which break easily to produce inhalable size fractions that are reported to cause lung diseases.

The main source of asbestos fibres in former mining areas is asbestos mine dumps and asbestos contaminated surface soil. Asbestos mine dumps in Limpopo Province are partially rehabilitated, while in Mpumalanga Province they are not rehabilitated and all these dumps are now under the care of government because the original owners have abandoned them. The settleable dust is the first indicator of airborne dust pollution and the rate of settleable dust rates was used to select the sites to be monitored.

A pilot study was conducted to test the performance of the ASTM D1739:1998 and ASTM D 1739:1970 methods. The method was further modified and optimized to measure asbestos load in settleable dust samples. A total ten sites located around vulnerable human settlements that are in close proximity to the abandoned asbestos mine dumps were chosen in Mpumalanga and Limpopo Provinces respectively. Airborne, surface and trapped dust samples were collected once a month around human settlements that are in close proximity to the abandoned asbestos mine dumps from April 2016 to June 2017. Airborne dust samples were collected using the official settleable dust monitoring method, the general particulate matter E-sampler and the official asbestos Air-Con 2 sampler. Surface dust was collected outdoors around the settleable dust collection units using a brush and dust pan and was stored in labeled zipper bags made of plastic material. Trapped dust samples were collected using sticky tape both indoors and outdoors around the window panes, on surfaces of furniture and on windscreens of old cars and were stored in labeled closed containers. Surface soil samples were also screened with the hand held asbestos analyser before collection.

The samples were extensively and carefully prepared and handled to avoid or minimize cross contamination using standard laboratory methods and were analysed using calibrated analytical instruments.

An adapted method (ASTMD 1739:1970) was used to determine the presence of asbestos hazard in a form of mineral count. This method was also used for the identification of asbestos and other minerals in different dust samples using the XRD technique. Physical features of all minerals such as the shape, size and type were also determined as part of the characterization process using the SEM-EDS technique.

The ASTMD1739:1998 method gave rise to higher retention of settleable dust, hence it was found to be more efficient. Unfortunately, this best performing method is not legislated or regulated by the government. This researcher concludes that the reasons could be due to the different shapes of the windshield designs (which means the different designs of windshields) at may make it difficult to standardize and control. However, this information gap provides an opportunity of a longer focused study of this method with the intention of finding a standardized windshield design that could be recommended for use in the country.

Secondly, the units that had both water and algaecide gave rise to higher settleable Mpumalanga. Three exceedances of 600 mg/m²/day of residential limit regulated through National Dust Control Regulation no.28 of 2013 presented in decreasing order in Limpopo were 2724 mg/m²/day at Site E, 1638 mg/m²/day at Site D and 834 mg/m²/day at Site B in the same month of March 2017 .

The XRF data of metal oxides, including these top three [Si(IV)O₂, Fe₂(III)O₃ and Al₂(III)O₃], confirm the dominance of silicate minerals in surface dust samples from both provinces. The XRD mineralogy data from filtered settleable dust show the dominance of the amphibole asbestos particulates ranging from 18 to 56 % in Limpopo province and 2.0 to 3.0 % in Mpumalanga province. Low presence of serpentine minerals with the highest being 2.0 % and 7.0 % in Limpopo and Mpumalanga provinces respectively. About 8.0 to 43 % of amphibole asbestos minerals were measured on trapped dust in Limpopo together with zero detection of serpentine.

No asbestos minerals were detected on trapped dust from Mpumalanga, despite the close proximity of the unrehabilitated asbestos mine dumps

All airborne asbestos fibres that were captured on the filter substrates were above the limit value of 100 f/mL of air. The highest airborne asbestos fibre and concentration counts measured were 40 fibres and 0,00434 f/mL concentration in October 2017 at Site A. The second highest fibre count concentration was measured in June with 0,00287 f/mL at Site A in September 2017 and 0,01085 f/mL at the Site D in June 2017 monitoring sites. Again, the highest in June 2017 with 0,00125 f/mL for Site A for Limpopo Province. In Mpumalanga the lowest asbestos fibre concentration which are below the OHSA no. 39 of 1993 and MDHS 39/4, 1995 0.1 f/mL and 100 f/mL. However, from the safety perspective all asbestos fibres or minerals inhaled are a hazard to human health. The study established that the adapted asbestos mineral count method succeeded in identifying and quantifying the asbestos minerals that existed in the settleable dust samples from the study areas. These outcomes were successfully validated with the test undertaken using both the official (Air Con 2 sampler) and unofficial (E-sampler) recognized method of asbestos fibre count. The adapted mineral count method provides the research community with an alternative, cost effective and user-friendly method of analysis.

Also, the validation methods gave additional new information. Of a total of 120 of exposed filter papers used in the official asbestos fibre Air Con 2 sampler, 28 filters had positive presence of asbestos fibres, making it 23% collection efficiency. And of the 100 exposed filter papers used in for E-samplers, only 8% collection efficiency was recorded. The results means that the official asbestos fibre Air Con 2 sampler has 23% more collection efficiency than the general particulate matter E-sampler for airborne asbestos monitoring. The impact of these results could also be that a general particulate matter high volume sampler could still be used for asbestos fibre monitoring in the absence of a specific and selective Air Con 2 sampler, as long as the user appreciates about 23% collection deficiency. These findings go a long way in helping to make air quality research domain accessible.

Since the ASTM D1739:1998 method has been found to perform better than the officially recognized method, this study recommends that the regulators of air quality in the country consider it. But, the method will first require some improvement and standardization particularly the different wind shield designs before it could be officially accepted as the method of collection and analyses for settleable dust. It is hoped that the air quality research community will take up the challenge.

Keywords: Abandoned and ownerless, Settleable dust, Airborne dust, Surface dust, Trapped dust, Adapted asbestos mineral count, Asbestos fibre count, XRD, XRF, SEM-EDS, PCM, Limpopo Province, Mpumalanga Province.

Sinopsis

Grond en ander geologiese materiale wat op die aardkors aangetref word, is bekend dat hulle ryk is in silikaatminerale wat natuurlik voorkom. Asbes is een van die veselagtige silikaatminerale wat hoofsaaklik in sommige streke van die Limpopo, Mpumalanga en Noord-Kaap Provinsies in Suid-Afrika ontgin is. Ondanks die staking van asbesmynbou in 2002 as gevolg van gepaardgaande gesondheidseffekte op mense, is daar steeds kommer oor moontlike blootstelling aan asbesvesels in die omgewing. 'n Enkele asbesvesel bestaan uit miljoene mikroskopiese naaldagtige vesels wat maklik breek om partikels van inasembare grootte te produseer wat volgens berigte longsiektes veroorsaak.

Die belangrikste bron van asbesvesels in voormalige myngebiede is asbesmynhope en besmette asbesoppervlakgrond. Asbesmynhope in Limpopo Provinsie word gedeeltelik gerehabiliteer, terwyl hulle in Mpumalanga Provinsie nie gerehabiliteer word nie, en al hierdie mynhope is nou onder die regering se toesig omdat die oorspronklike eienaars die mynhope verlaat het. Die neerslagbare stof is die eerste aanduiding van stofbesoedeling in die lug en is gebruik om die terreine wat gemoniteer moet word, te kies.

'n Loodsstudie is uitgevoer om die prestasie van die ASTM D1739:1998 en ASTM D1739:1970 metodes te toets. In die loop van die studie is 'n amptelike ASTM D1739:1970 metode gebruik en toegepas vir die versameling van neerslagbare stofmonsters. In Mpumalanga en Limpopo Provinsies respektiewelik is daar altesaam tien (10) terreine gekies rondom kwesbare menslike nedersettings wat naby die verlate asbesmynhope geleë is. Stofmonsters in die lug, oppervlak en wat vasgevang is, is een keer per maand versamel vanaf April 2016 tot Junie 2017 rondom menslike nedersettings in die nabyheid van die verlate asbesmynhope. Stofmonsters in die lug is versamel volgens die amptelike neerslagbare stofmoniteringsmetode, die E monsternemer en die Air-Con 2 monsternemer. Oppervlakstof is buite met behulp van 'n kwas en stofpan rondom die neerslagbare stofopvangenhede opgevang en is in gemerkte ritsakke van plastiek materiaal geberg. Stofmonsters wat vasgevang is, is met behulp van kleeflint, binne en buite, om vensterruite, op meubeloppervlaktes en

op voorruitte van ou motors versamel, en is in gemerkte geslote houers geberg. Oppervlakgrondmonsters is ook voor versameling met die draagbare asbesanaliseerder gefilter.

Die monsters is breedvoerig en sorgvuldig voorberei en hanteer om kruisbesmetting tot 'n minimum te beperk deur gebruik te maak van standard laboratoriummetodes en is ontleed met behulp van gekalibreerde analitiese instrumente.

'n Aangepaste metode is gebruik om die teenwoordigheid van asbesgevaar in 'n vorm van mineraaltelling te bepaal. Hierdie metode is ook gebruik vir die identifisering van asbes en ander minerale in verskillende stofmonsters met behulp van die XRD tegniek. Die fisiese kenmerke van alle minerale soos die vorm, grootte en tipe is ook bepaal as deel van die karakteriseringsproses met behulp van die SEM-EDS tegniek.

Die ASTM D1739:1998 metode het gelei tot 'n hoër retensie van neerslagbare stof, en daarom is gevind dat dit doeltreffer is. Ongelukkig word hierdie metode wat die beste presteer nie deur die regering gewettig of gereguleer nie. Hierdie navorser kom tot die gevolgtrekking dat die redes kan wees as gevolg van die verskillende vorms van die voorruitontwerpe wat dit moeilik kan maak om dit te standaardiseer en te beheer. Hierdie inligtingsgaping bied egter 'n geleentheid tot 'n langer gefokusde studie van hierdie metode met die doel om 'n gestandaardiseerde voorruitontwerp te vind wat aanbeveel kan word vir gebruik in die land.

Tweedens het die eenhede wat beide water en alge-suurwater gehad het, gelei tot 'n hoër neerslagbare stof in Mpumalanga Provinsie. Drie oorskrydings wat in dalende volgorde in Limpopo aangebied is, was 2724 mg/m²/dag op perseel E, 1638 mg/m²/dag op perseel D en 834 mg/m²/dag op perseel B in dieselfde maand van Maart 2017.

Die XRF data van metaaloksiede, met inbegrip van hierdie top drie [Si(IV)O₂, Fe₂(III)O₃ en Al₂(III)O₃], bevestig die oorheersing van silikaatminerale in oppervlakstofmonsters van beide provinsies. Die XRD mineralogiedata van gefiltreerde, neerslagbare stof toon die oorheersing van die amfibool asbesdeeltjies wat wissel tussen 18 en 56 % in Limpopo Provinsie en 2.0 en 3.0 % in Mpumalanga Provinsie. Daar is 'n lae teenwoordigheid van serpentynminerale met die hoogste onderskeidelik 2.0 % en 7.0 % in die Limpopo en Mpumalanga Provinsies.

onderskeidelik. Ongeveer 8.0 tot 43 % van die amfibool asbesminerale is op vasgevangde stof in Limpopo gemeet, tesame met geen opsporing van serpentyn.

Geen asbesminerale is opgespoor in die vasgevangde stof van Mpumalanga nie, ondanks die nabyheid van die ongerehabiliteerde asbesmynhope.

Alle asbesvesels in die lug wat op die filtersubstrate vasgelê is, was bo die grenswaarde van 100 f/mL lug. Die hoogste asbesvesel en konsentrasietellings in die lug gemeet, was 40 vesels en 'n konsentrasie van 2.083 f/mL in Oktober op Terrein A. Die volgende hoogste veseltellingkonsentrasie is in Junie gemeet met 6.590 f/mL op die Terrein A en 5.272 f/mL op die Terrein D moniteringsterreine. In Mpumalanga was die hoogste asbesveselkonsentrasie 2.190 f/mL in Junie en 2.083 f/mL in November op Terrein D. Uit 'n veiligheidsperspektief is alle asbesvesels of minerale wat ingeasem word egter 'n gevaar vir die mens se gesondheid. Die studie het vasgestel dat die aangepaste asbesmineraaltellingmetode daarin geslaag het om die asbesminerale wat in die neerslagbare stofmonsters uit die studiegebiede bestaan te identifiseer en te kwantifiseer. Hierdie uitkoms is suksesvol bekragtig met die toets wat onderneem is met behulp van die amptelik erkende metode vir die telling van asbesvesel. Die aangepaste mineraaltellingmetode bied aan die navorsingsgemeenskap 'n alternatiewe, koste-effektiewe en gebruikersvriendelike ontledingsmetode.

Aangesien daar gevind is dat die ASTM D1739:1998 metode beter presteer as die amptelik erkende metode, beveel hierdie studie aan dat die reguleerders van luggehalte in die land dit oorweeg. Maar die metode sal eers verbetering en standaardisering verg, veral die verskillende windsfermentwerpe voordat dit amptelik aanvaarkan word as die metode om neerslagbare stof te versamel en te ontleed. Daar word gehoop dat die gemeenskap wat luggehalte navors die uitdaging sal aanpak.

Sleutelwoorde: Verlate en eienaarlose, neerslagbare stof, stof in die lug, oppervlakstof, vasgevangde stof, aangepaste asbesmineraaltelling, asbesveseltelling, XRD, XRF, SEM-EDS, PCM, Limpopo Provinsie, Mpumalanga Provinsie.

Sengwalwakopana

Mabu le dišomišwa tše dingwe tša bothutaswika tše di hwetšagalago bokagodimo ba Lefase di tsebja di e na le diminerae tše dintši tša tlhago tše di diragalago ka tlhago. Marela ke e ngwe ya diminerae tše di nago le dimela tše di ntši kudu tše di bego di epšwa kudu mafelong a mangwe a diphrofentshe "diphrofentsheng tša Limpopo, Mpumalanga le North Cape Afrika Borwa. Le ge go feditšwe go epšwa marela ka lebaka la ditlamorago tše amanago le maphelo a batho ka 2002, go na le pelaelo malebana le go utullwa ga malwetši a *marela*. *Fibre* ke ye ngwe ya *marela* ye e dirilwego ka maekrosekopiki tše dimilione tše di ka senyegago bonolo go tšweletša khemobonolo yeo e hlamago malwetši a mafahla.

Sehlodikgolo sa malwetši a marela mafelong a mathomo ao go bego go le meepo ke sekoti sa *marela* le mabu a ka godimo ga *marela*. Dikoti tša meepo ya *Marela* Phrofentsheng ya Limpopo di mpšhafaditšwe ka tsela ye itšego, eupša Phrofentsheng ya Mpumalanga ga se tša mpšhafatšwa gomme mafelo a ka moka a laolwa ke mmušo gobane beng ba tšona ba di tlogetše. Lerole le ka rarollwago ke sešupopele sa tšhilafalo ya moya e dirwago ka moya gomme se be se šomišwa go kgetha mafelo ao a loketšwego go hlokomelwa.

Go ile gwa dirwa tekolo ya go leka tšhomo ya mekgwa ya ASTM D1739: 1998 le ASTM D 1739: 1970. Ge re ntšere tšwela pele ka thuto, go šomišitšwe mokgwa wa semmušo wa ASTM D1739: 1970 gomme wa šomišwa lebakeng la go kgoboketša sampole ya lerole e ka rarollwago. Mafelo a lesome (10) a hweditšwe kgauswi le bodulo ba batho bjo bo lego kotsing ka dikoti tša meepo ya *marela* di ile tša kgethwa diphrofentsheng tša Mpumalanga le Limpopo ka go latelana. Disampole tša moya tša ka godimo ga lefase, godimo le tše di khutilego di ile tša kgoboketšwa ga tee kgwedding kgauswi le bodulo ba batho tše di bego kgauswi kudu le dikoti tša meepo ya *marela* go tloga ka la 2016 Mopitlo go fihla ka Phupu 2017. Mehuta ya lerole ye sepetšwago ke moya e ile ya kgoboketšwa go šomišwa mokgwa wa semolao wa go tšweletša lerole, E-sampler le sampole ya Air-Con 2. Lerole la ka godimo le be le kgoboketšwa ka ntle go rarela dikarolo tša go kgoboketša lerole go šomišwa poratšhe le pane ya kota gomme

Dintlha tša XRF tša di-oxide tša tšhipi, go akaretša tše tše tharo tša godimo [Si (IV) O₂, Fe₂ (III) O₃ le Al₂ (III) O₃], di tiša boleng bo phagameng ba diminerae tša silrate mehuteng ya lerole ye e tšwago diphrofentsheng ka bobedi. Dintlha tša XRD tša *mineralogy* tše di tšwago leroleng le tšhilafatšong di ka tšewa di bontšha phelo ya *marela* ya *amphibole* go tloga go 18 go iša go 56% phrofentsheng ya Limpopo le 2.0 go iša go 3.0% phrofentsheng ya Mpumalanga. Bogonatlasa ba diminerae tša *serpentine* tše phagameng ka go fetišiša e le 2.0% le 7.0% diphrofentsheng tša Limpopo le Mpumalanga ka go latelana. Go lekana 8.0 go iša go 43% ya diminerae tša *marela* tše lekantšwego di ile tša lekanywa leroleng le ageeletšwego ka Limpopo gammogo le go utullwa ga *serpentine*.

Ga go na diminerae tša *marela* tše di hweditšwego leroleng le ageeletšwego le tšwago Mpumalanga, le ge e le kgauswi kgauswi le dikoti tša mope wa maraba wa *marela* se a mpšhafatšwago.

Mehuta ka moka ya moya ya *marela* ye e bego e swerwe ka gare ga moya o bego o le ka godimo wa boleng ba moya wa 100 f /mL. Mohuta o phagamego go fetišiša wa moya wa *marela* le dipalo tša mahlorišo a lekantšwego e be e le tše 40 le bogolo ba 2.083 f /mL ka Diphallane go Site A. Tekanyomahloriš e latelago ya *fiber* e lekantšwe Phupu ka 6.590 f /mL go Site A le 5.272 f /mL Site D mafelong a tlhahlobo. Nageng ya Mpumalanga, di-*fibres* tša *marela* tše phagamego ka go fetišiša e be e le 2.190 f /mL ka Phupu le 2.083 f /mL ka Dibatsela go Site D. Le ge go le bjalo, go latela ponego ya tšhireletšo, *fibres* ka moka tša *marela* goba diminerae tše di hengwago di kotsi maphelong a botho. Boithuto bo bo utullotše gore mokgwa wo lekantšwego wa *marela* o bontšhitšwegošupo o atlegile go kgetholla le go hlakola diminerae tša *marela* tše di bego di le gona ka gare ga disampolo tša lerole le tšwago mafelong a boithuto. Sephetho se se netefaditšwe katlego le tlhahlobo ye e dirilwego e šomišwago mokgwa wo amogetšwego ke molao wa *marela fiber*. Mokgwa o lekantšwego wa diminerae o thuša setšhaba sa dinyakišišo ka mokgwa o mongwe wa tlhahlobo ye e šongwago, gabotse e bile ye botho.

Go tloga go mokgwa wa ASTM D1739: 1998 o hweditšwe o šoma gabotse go feta mokgwa wo amogetšwego ke molao, thuto ye e šupetša gore balaodi ba boleng ba moya nageng ba e nagane. Empa, mokgwa wo o tla hloka mpšhafatšo le maemo pele

le bolokelwa ka mekotleng e nago le zipper ye dirilwego ka polasetiki. Sampole ya lerole le le bego le gaeletšwe le ile la kgoboketšwa ka theipi ya go momela bokagareng le bokantle bja morumofasetere, mabotong a phahlo, le godimo ga galasebokapele dikoloing tša kgale gomme tša bolokwa ka gare ga didirišwa tšeo di makilwego. Disampolo tša mabu a ka godimo di be di hlahlobjwa gape ka mokgwa wa go kgwa ka letsogo ke mohlalobi wa *marela* pele go kgoboketšwa.

Disampole di be di lokišitšwe kudu ebile di dirilwe ka tlhoko go efoga tšhilafalo ka mekgwa ye tlwaelegilwego ya laporatori gomme ba e hlahloba ba šomiša didirišwa tša go hlahloba.

Mokgwa o ikgethilego o šomišwa go hwetša bogona ba kotsi ya *marela* ka mokgwa wa palo ya diminerae. Mokgwa wo o be o šomišitšwe gape le go bošupong ba *marela* le diminerae tše dingwe ka gare ga disampole tše di fapanego tša lerole go šomišwa mokgwa wa XRD. Dibepegopono tša diminerae ka moka go swana le sebopego, bogolo le mohuta le tšona di be di tšewa e le karolo ya tshepetšo ya pharodipataka go šomišwa mokgwa wa SEM-EDS.

Mokgwa wa ASTM D1739: 1998 o ile wa dira gore go bolokwe lerole le phagameng ka go fetolegago, ka gona go hweditšwe gore le šoma gabotse kudu. Ka bomadimabe, mokgwa wo o tšweletši kudu ge o ngwadišwa ke molao go mmušo. Monyakišiši wo o phetha ka gore mabaka e ka ba ka lebaka la dibopego tše di fapaneng tša meralo ya setsi sa moya se se ka dirago gore go be boima go tseba le go laola. Le ge go le bjalo, sekgoba se sa tshedimošo se fa monyetla wa go ithuta nepišo e telele ya maikemišetšo a go hwetša moralo o tiišitšwego wa moya o ka šišinywago gore o šomišwe ka nageng.

Ya bobedi, diyuniti tše di bego di e na le meetsi le *algaecide* di ile tša tšweletša maemo a phagamego Mpumalanga Phrofentsheng. Ditekanyetšo tše tharo tše di tšweleditše ka tatelano ya taolo e fokotšegago e be e le 2724 mg/ m²/ letšatši go Site E, 1638 mg / m²/ letšatši go Site D le 834 mg/ m²/ letšatši go Site B kgwedding ye tee ya Hlakola 2017

kudu meralo ye fapaneng ya thebe ya moya pele e ka amogelwa ke molao e le mokgwa wa go kgoboketša le go sekaseka lerole le le ka rarolwago. Re tshepa gore setšhaba sa dinyakišišo tša boleng ba moya se tla tšea bothata bo.

Mantšu a bohlokwa: lahlilwego le hlokobeng, Lerolesesane, Lerole le le bego le moya, lerole le le ageeletšwego, Lerole la diminerae tša *marela*, palo ya dibjalo tša *Marela*, XRD, XRF, SEM-EDS, PCM, Phrofentsheng ya Limpopo, Phrofentsheng ya Mpumalanga.

Lingoloa tse ling

Mobu le lisebelisoa tse ling tsa jioloji tse fumanehang bokaholimo ba Lefatše li tsejoa li na le liminerale tse ngata tsa tlhaho tse etsahalang ka tlhaho. Asbestos ke e 'ngoe ea liminerale tse nang le silika e ngata e neng e chekoa haholo libakeng tse ling tsa liprofinse tsa "liprofinse tsa Limpopo, Mpumalanga le North Cape Afrika Boroa. Leha ho felisoa morafo oa asbestos ka lebaka la litlamorao tse amanang le bophelo bo botle ba batho ka 2002, ho ntse ho na le ts'oenyeho mabapi le ho pepesetsoa ha tikoloho likhoele tsa asbestos. Fiber e le 'ngoe ea asbestos e entsoe ka likhoele tse limilione tse kang nale tse tsoang habonolo ho hlahisa likaroloana tse sa bonoeng tse tlalehang libaka-mafuamatšo.

Mohloli o ka sehloohong oa likhoele tsa asbestos libakeng tseo pele e neng e le tsa meepo ke lithako tsa asbestos le mobu o silafetseng oa asbestos. Likotlo tsa merafo ea Asbestos Profinseng ea Limpopo li nchafalitsoe ka tsela e itseng, athe Profinseng ea Mpumalanga ha e nchafatsoe 'me libaka tsena kaofela li laoloa ke mmuso hobane beng ba tsona ba ba lahlile. Lerōle le ka rarolloang ke letšoao la pele la tšilafalo ea moea e tsoang ka moea mme le ne le sebelisetsoa ho khetha libaka tseo li lokelang ho-shebelloa. Ho ile ha etsoa boithuto ba ho leka ts'ebetso ea mekhoha ea ASTM D1739: 1998 le ASTM D 1739: 1970. Ha re ntse re tsoela pele ka thuto, ho sebelisitsoe mokhoa oa semmuso oa ASTM D1739: 1970 'me oa sebelisoa bakeng sa ho bokella sampole ea lerōle e ka rarolloang. Sebaka sa libaka tse leshome (10) tse fumanehang haufi le bolulo ba batho ba tlokotsing tse haufi le libaka tse lahliloeng tsa meepo ea asbestos li ile tsa khethoa liprofinse tsa Mpumalanga le Limpopo ka ho latellana. Lisampole tsa moea tse ka holim'a lefatše, holimo le tse patiloeng li ile tsa bokelloa hang ka khoeli ho potoloha libaka tsa bolulo tsa batho tse haufi haholo le libaka tse lahliloeng tsa moepo oa asbestos ho tloha ka Mmesa 2016 ho fihlela ka Phuptjane 2017. Mefuta ea lerōle e tsamaisoang ke moea e ile ea bokelloa ho sebelisoa mokhoa oa semolao oa ho hlahisa lerōle, E-sampler le sampole ea Air-Con 2. Lerōle le kaholimo le ne le bokelloa ka ntle ho potoloha likarolo tsa ho bokella lerōle le sebelisa brashi le pane ea patsi mme le bolokiloe ka mekotleng e nang le zipper e entsoeng ka thepa ea polasetiki. Mehlala ea lerōle e neng e tsoasehile e ile ea bokelloa ho sebelisoa theipi e khangoang ka tlung le kantle kahare ho lifensetere, ka holim'a thepa ea ka tlung le lifensetereng tsa likoloi tsa khale 'me li bolokiloe ka har'a

lisebelisoa tse koetsoeng. Meetso ea mobu e kaholimo le eona e ile ea hlahlojoa ka letsoho le ts'oaroang ka asbestos pele ho pokello. Mehlala e ne e hlophisitsoe haholo ebile e entsoe ka hloko ho qoba ho silafatsa kapa ho fokotsa tšilafalo ea tšebeliso ea mekhoa e tloaelehileng ea laboratori mme e ile ea hlahlojoa ho sebelisoa lisebelisoa tsa tekanyetso.

Mokhoa o ikhethileng o sebelisitsoe ho fumana ho ba teng ha kotsi ea asbestos ka mokhoa oa palo ea liminerale. Mokhoa ona o ne o boetse o sebelisoa bakeng sa ho khetholla asbestos le liminerale tse ling ka har'a disampole tse fapaneng tsa lerōle ho sebelisoa mokhoa oa XRD. Litšobotsi tsa 'mele tsa liminerale tsohle tse kang sebopeho, boholo le mofuta le tsona li ne li nkuoa e le karolo ea ts'ebetso ea sebopeho ho sebelisa mokhoa oa SEM-EDS. Mokhoa oa ASTM D1739: 1998 o ile oa etsa hore ho bolokoe lerōle le phahameng ka ho fetelletsa, ka hona ho fumanoa hore le sebetsa hantle haholo. Ka bomalimabe, mokhoa ona o atlehileng ka ho fetisisa ha o ngolisoe ke molao kapa 'muso. Mofuputsi enoa o phethela ka hore mabaka a ka ba teng ka lebaka la sebopeho se fapaneng sa meralo ea setsi sa moea se ka etsang hore ho be thata ho tseba le ho laola. Leha ho le joalo, lekhalo lena la tlhaiso-leseling le fana ka monyetla oa ho ithuta ho tsepameng molemong oa mokhoa ona ka sepheo sa ho fumana moralo o tiisitsoeng oa moea o ka kothalletsoang hore o sebelisoa ka har'a naha.

Ya bobedi, diyuniti tse neng di na le metsi le algaecide li ile tsa hlahisa maemo a phahameng a ho tsetsahala Mpumalanga. Litekanyetso tse tharo tse fanoeng ka tatellano ea taolo e fokotsehang e ne e le 2724 mg/m²/letsatsi ho Site E, 1638 mg/m²/letsatsi ho Site D le 834 mg/m²/letsatsi ho Site B ka khoeli e tšoanang ea Hlakubele 2017.

Lintlha tsa XRF tsa li-oxide tsa tšepe, ho kenyelletsa tsena tse tharo tse holimo [Si (IV) O₂, Fe₂ (III) O₃ le Al₂ (III) O₃], li tiisa boleng bo phahameng ba liminerale tsa silicate mefuteng ea lerōle e tsoang liprofinseng ka bobeli. Lintlha tsa XRD tsa mineralogy tse tsoang lerōleng le ts'ilafatsoang li ka nkuoa li bonts'a phello ea asbestos ea amphibole ho tloha ho 18 ho isa ho 56% profinseng ea Limpopo le 2.0 ho isa ho 3.0% profinseng ea Mpumalanga. Boteng bo tlase ba liminerale tsa linoha tse phahameng ka ho fetisisa e le 2.0% le 7.0% liprofinseng tsa Limpopo le Mpumalanga ka ho latellana. Hoo e ka

bang 8.0 ho isa ho 43% ea liminerale tsa asbestos tse lekantsoeng li ile tsa lekanngoa lerōleng le ts'oaroang ho la Limpopo hammoho le ho sibolloa ha noha. Ha ho na liminerale tsa asbestos tse fumanoeng lerōleng le tsubelletsoeng le tsoang Mpumalanga, leha ho le haufi le marang-rang a litopo tsa asbestos tse sa ntlafatsoang.

Mefuta eohle ea moea e kang asbestos e neng e hapiloe kahare ho moea o ne o le kaholimo ho boleng ba moea oa 100 f /mL. Mofuta o phahameng ka ho fetisisa oa moea oa asbestos le lipalo tsa mahloriso tse lekantsoeng e ne e le likhoele tse 40 le boholo ba 2.083 f /mL ka Mphalane ho Site A. Khakanyo e latelang ea fiber fiber e latelang e lekantsoe ka Pherekhong ka 6.590 f /mL ho Site A le 5.272 f /mL setsing D libaka tsa tlhahlobo. Naheng ea Mpumalanga, li-fiber tsa asbestos tse phahameng ka ho fetisisa e ne e le 2.190 f /mL ka Phuptjane le 2.083 f /mL ka Pulungoana ho Site D. Leha ho le joalo, ho latela pono ea ts'ireletso, likhoele tsohle tsa asbestos kapa liminerale tse kentsoeng li kotsi bophelong ba motho. Boithuto bo fumane hore mokhoa o lekantsoeng oa "asbestos" o ntlafalitsoeng o atlehile ho tseba le ho hlakisa liminerale tsa asbestos tse neng li le teng ka har'a mehlala ea lerōle e tsoang libakeng tsa boithuto. Sephetho sena se netefalitsoe ka katleho le tlhahlobo e entsoeng e sebelisang mokhoa o amohetsoeng ka molao oa asbestos fiber count. Mokhoa o lekantsoeng oa liminerale o thusa sechaba sa lipatlisiso ka mokhoa o mong oa tlhahlobo o sebetsang, o sebetsang hantle ebile o sebelisang botsoalle. Ho tloha ha mokhoa oa ASTM D1739: 1998 o fumanoa o sebetsa hantle ho feta mokhoa o amohetsoeng ka molao, thuto ena e khothaletsa hore batsamaisi ba boleng ba moea naheng ba e nahane. Empa, mokhoa ona o tla hloka ntlafatso le maemo pele haholo mealo e fapaneng ea thebe ea moea pele e ka amoheloa ka molao e le mokhoa oa ho bokella le ho sekaseka lerōle le ka rarolloang. Re tšepa hore sechaba sa lipatlisiso tsa boleng ba moea se tla nka bothata bona.

Mantsoe a bohlokoa: U lahliloe khrehloa ebile ha u na thepa, U na le lerōle le tsitsitseng, Lerōle le nang le moea, lerōle le tsubelletsoeng, palo ea liminerale tsa asbestos, palo ea li-asbestos, XRD, XRF, SEM-EDS, PCM, profinseng ea Limpopo, profiseng ea Mpumalanga.

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List of Abbreviations

APPA	Atmospheric Pollution Prevention Act
ASTM	American Society for Testing and Material
ATS	American Thoracic Society
ATW	Asbestos Toxicology Working
ATSDR	Agency for Toxic Substance and Disease Registry
ART	Asbestos Relief Trust
BGB	Barberton Greenstone Belt
CEC	Cation Exchange Capacity
CSMI	Center for Sustainability in Mining and Industry
CRSA	Constitution of Republic of South Africa
DTEC	Department of Tourism Environmental Conservation
GDP	Gross Domestic Products
GEFCO	Griqualand Exploration and Finance Company Ltd
HSDB	Hazardous Substances Data Bank
IARC	International Asbestos Registry Center
IDP	Integrated Development Plans
KRT	Kgalagadi Relief Trust
MDHS	Methods for the determination of hazardous substances
MI & FERS	Ministry of International and Foreign Economic Relation of the Sverdlovsk Region
MPRDA	Mineral Petroleum Resources Development Act
MYEP	Mid-Year Estimates Population
NEMA	National Environmental Management Act
NEMAQA	National Environmental Management: Air Quality Act
NDCR	National Dust Control Regulations
NTP	National Toxicology Program
PM ₁₀	Dust with an average aerodynamic diameter (d ₅₀) less than 10 µm
PM _{2.5}	Dust with an average aerodynamic diameter (d ₅₀) less than 2.5 µm

PLFA	Phospholipids Fatty Acid
PUR	Pneumoconiosis Research Unit
SAI	South African Information
SANS	South African National Standards
SAWS	South African Weather Services
SAIMR	South African Industry and Mining Resources
SEM-EDX	Scanning Electron Magnetic-Energy Dispersive X-Ray
SER	Society for Ecology Restoration
SOP	Standard Operation Procedure
TEM	Transmission Electron Microscopy
US-EPA	United States – Environmental Protection Agency
WHO	World Health Organisation
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence

Research output from this work

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1. Moja SJ, **Kwata MG**, Sebesho LM, Masindi KG, and Mtunzi F. 2016. Characterization of surface and trapped dust samples collected around human settlements that are in the vicinity of old mine tailings in Mpumalanga Province. South Africa. Journal of Earth Science and Climate Change.7.360. DOI: 10.4172/2157-7617.1000360. pp: 1-7.
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1. **Kwata MG** and Moja SJ. 2016. "Characterization of dust fallout samples around some ownerless and abandoned asbestos mine dumps in Mpumalanga Province. *Oral presentation*. Council for Geosciences Conference. CSIR Convention Center. 04th - 05th February.
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International Geological Conference. Cape Town Convectional Center. South Africa. 27th August – 04th September.

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7. Mashalane TB, Moja SJ, **Kwata MG**, Masindi K, Mtyelwa O, Malatji MR and Novhe NO. 2017. Mineralogical characterization of dust fall and surface samples from abandoned asbestos mine dumps in Northern Cape, South Africa. *Poster Presentation*. National Association of Clean Air Conference. Cedar Woods. Sandton. South Africa. This poster won the best scientific poster award. 4th - 6th October.

Other Special Scientific Awards

1. The author was awarded with the Scientific Excellence at the Council for Geoscience Year End Function, 8 December 2017.
2. The supervisor received the Senior Scientific Excellence-Geological resources Award at the Council for Geoscience Year End Function, December 2018.

CHAPTER 1: INTRODUCTION

1.1 Introduction

This chapter gives a detailed history of mining in South Africa and the background on abandoned asbestos mining per provinces in the country. The chapter also contains the problem statement, aims and objectives of the research and description of the method applied for this research.

1.2 History of the mining industry in South Africa

South African mining is the leading force behind the history and development of the largest economy in Africa (Kahn, 2013; Pali, 2015). The mining of gold, diamond, coal, platinum and iron commodities has contributed immensely to the South African economy. For example, in 1970 the local mining industry contributed about 21 % of the Gross Domestic Product (GDP) (South African statistics, 2015). In South Africa, the mining sector led to an improved economy with GDP of about 65 % (McCourt, 2012). Large gold deposits were discovered in 1886 in the Witwatersrand (White, 2003).

South Africa is the world's largest producer of chrome, manganese, platinum, vanadium and vermiculite (Department of Mineral Resources and Energy (DMRE), 2007). The country accounts for over 10 % of the global gold production (Chamber of Mines of South Africa, 2017); is the fourth largest producer of diamonds (Global natural diamond forecast, 2017); is ranked 5th in the coal production globally (Statistic South Africa (Stats SA): Electricity generated and available for distribution, 2015) and holds 40 % of the world's total gold reserves found in Witwatersrand area. Iron ore is mined in Sishen and Thabazimbi and more than 80 % of South Africa's product output comes from these areas (Kumba iron ore limited, 2010). The north-western part of South Africa is famous for platinum and gold mining which accounts for 90% of South Africa's platinum production (SAMP, 2016).

The largest platinum producing mines are located in the Rustenburg areas (Africa mining iQ, 2017). Diamonds are mined in Koster, Lichtenburg, Bleomhof and Christiana (Mining in North West overview, 2017). Major coalfields are situated in the Highveld and Lowveld regions and Witbank and Ermelo are the major mining hubs (Jeffrey, 2005). Coal production meets almost 80 % of South Africa's primary energy needs (Banks et al., 2011).

1.3 Background of asbestos mining in South Africa

Asbestos refers to a class of mineral silicate which crystallizes into fibres that may be long and thin in an ore body (Harrington and McGlsham, 1998). Asbestos fibres can be classified into two groups of minerals, namely serpentine and amphibole, which provide a historical usefulness due to their extraordinary tensile strength, poor heat conduction and relative resistance to a chemical attack (Mossman, 2003). Local asbestos mining started in the 1800's in the Northern Cape Province, followed by Limpopo Province and then Mpumalanga Province (Kwata *et al.*, 2017). Only long asbestos fibres were useful to mining industry for manufacturing reasons (IARC, 2012, Kahn, 2013). Short fibres were discarded together with other waste material or rubble and formed heaps of dumps, which are now a major secondary point source of asbestos.

Long fibres of asbestos were used to manufacture building materials, cement, roofing of houses and brake pads for vehicles (International Agency for Research on Cancer (IARC, 2012)). Globally, South Africa was the third largest asbestos producer in the 1970s, behind Canada and the USSR (Abratt *et al.*, 2002). The asbestos mining industry in South Africa reached its peak in 1977 and employed 200 000 miners and achieved an output of 380 000 tons (Nelson *et al.*, 2011). The subsidiaries of the British firms, Cape Asbestos Pty, Turner and Newall, together with Griqualand Exploration and Finance Company Ltd (Gefco), owned the enormous asbestos mines in South Africa South African Information (SAI, 2008). Asbestos mining in South Africa was banned in 2001 due to its risk on human health and environment.

The Delerict & Ownerless asbestos mine dumps refer to asbestos mine dumps which were operated when environmental management was not regulated in South Africa (before the Minerals Act no. 50 of 1991).

Also, owners or operators or holders of mining rights or leases can no longer be traced or they have abandoned the mines which are no longer in operation; they are not being maintained or rehabilitated and impacts associated with them (health and environment) are not being mitigated and managed Mineral Petroleum Development Act (MPDRA, 2004).

The D&O asbestos mine dumps were abandoned because of the environmental compliance legislations were weak (before the Minerals Act no.5 of 1991). (See Figure 1.1 below).



Figure 1.1: Abandoned and ownerless asbestos mine dumps, former miners hostel and unsealed shafts in Limpopo Province

Old and abandoned asbestos mine dumps have left a major environmental and health problem which is still a challenge to the Department of Minerals and Resources with regard to their rehabilitation (Moja *et al.*, 2016). The state is in the process of rehabilitating all asbestos mines on public land in South Africa due to associated environmental and health problems. Pollutants on these elevated unrehabilitated asbestos mine dump are easily spread around by wind and/or rain water.

Figure 1.2 shows the three asbestiform minerals of concern which occur in the veins/cracks of rock seams as bundles of fibres that break easily (Hodgson, 1977). Each fibre is composed of millions of microscopic needle like structures called fibrils (Ushiki, 2002).

These minerals were mined and milled locally and include chrysotile (whitish / greyish: $\text{Mg}_3\text{Si}_2\text{O}_5 (\text{OH})_4$) from Mpumalanga Province which is part of the serpentine group, amosite [brownish: $(\text{Mg,Fe})_7\text{Si}_8\text{O}_{22} (\text{OH})_2$] from Limpopo Province and crocidolite [bluish: $\text{NaFe}_3^{2+}\text{Fe}_2^{3+}\text{Si}_8 (\text{OH})_2$] from Northern Cape Province, both being part of the amphibole asbestos group.



Figure 1.2: Three asbestiform minerals

South Africa was once the global leader in the production of crocidolite and amosite, supplying approximately 97 % of the world's crocidolite and practically all of the world's amosite (Hart, 1988).

Asbestos mining in South Africa has been banned but that has not minimized the use of asbestos-containing materials in the country (Nelson *et al.*, 2011). Disposal of asbestos materials and the maintenance of asbestos dump sites still occur which continue to threaten the health and environment of South Africans (Abratt *et al.*, 2002). Between 1910 and 2002, South Africa mined more than 10 million tons of asbestos.

The last of the nation's asbestos mines ceased production in 2001 and closed down the following year (McCulloch, 2003). Asbestos minerals were mined locally mainly for export purposes because of the wide application of asbestos in commercial applications; long asbestos fibres were commercially used while short asbestos fibres were discarded.

This is the reason behind abandoned and ownerless mine dumps (Moja *et al.*, 2016). Asbestos has been used in the following: cement building material, pipework lagging, insulating mattresses and rope, fire resistant insulation boards and sprayed fire-proofing products.

The other uses of asbestos products were for floor tiles and coverings, water and sewage pipes, gas masks, friction materials for vehicles brakes and clutches. It was also used for lifts and machinery, boilers and pipework which were lagged with asbestos products in hospitals, power stations and throughout heavy industry (USEPA, 2008).

South Africa outlawed all types of asbestos by 2008, but the once-lucrative industry has left the environment polluted. Asbestos exposure risks continue to threaten the well-being of South Africans to this day (SAI, 2008).

1.4 Environmental legislations applicable in mining in South Africa

Environmental legislation was developed with the intention of guiding the mining companies to prevent, minimize and mitigate environmental contamination.

The Minerals Act (Act no. 50 of 1991) is the first Act indicating the rehabilitation responsibilities of mine operations in South Africa. The Act gave a detailed explanation in section 12 that the holder of mining authorization remains liable for complying with the relevant provisions of the Act until a certificate of mine closure has been issued to the effect that the said provisions have been complied with (Nel, 2006). South African legislation enforces a clear obligation on mining companies to prevent environmental effects and defines clear responsibilities associated with mine rehabilitation and closure. South African Acts and Regulations should control rehabilitation activities according to legal requirements. However, the core of these requirements is restricted in six key pieces of legislation and one standard namely:

- Atmospheric Pollution Prevention Act (APPA) (Act no. 45 of 1965);
- National Environmental Management: Air Quality Act (AQA) (Act no. 39 of 2004);

- The Constitution of the Republic of South Africa (CRSA) (Act no. 108 of 1996);
- The National Environmental Management Act (NEMA) (Act no. 107 of 1998);
- The Mineral and Petroleum Resources Development Act (MPRDA) (Act no. 28 of 2002);
- South Africa National Standards (SANS) 1929, 2004).

Atmospheric Pollution Prevention Act (APPA) Act no. 45 (RSA, 1965) states that air pollution is controlled at sources, declares the smoke free residential zones and Sulphur (II) Oxide limitations and fragmented source control. The focus of the act is the listed point sources pollution; sources not linked to impacts; and lack of public involvement and poor access to information.

National Environmental Management: Air Quality Act (NEMAQA) Act no. 39 of 2004 was enforced when the air quality management responsibilities shifted from national to provincial and local governments; the focus is on the receiving environment (instead of sources); involves the identification of priority areas, pollutants and sources; all point sources are addressed and not only scheduled/listed ones; encourages public participation and easy access to information.

National Dust Control Regulations (NDCR) no. 827 of 2013 was adopted for the data collection and analysis of settleable dust and single dust bucket unit ASTM D 1739-1970 was used as a reference method for the research and data interpretation. Section 24 of Constitution Republic of South Africa (CRSA) no.108 of 1996 states that everyone has the right to an environment that is not harmful to the health or well-being. It also states that everyone has the right to have the environment protected, through reasonable and other legislative measures that prevent pollution and ecological degradation, promote conservation and secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development. National Environmental Management Act (NEMA) Act no. 107 of 1998 encourages the prevention, minimisation and remediation of environmental pollution and degradation of the environment enforcing the polluter pays principle.

According to the MPRDA (Act no. 28 of 2002) section 38 (1) (d), any person who is a holder of a reconnaissance permission, prospecting right, mining right, mining permit or retention permit must, as far as it is reasonably accountable, rehabilitate the environment affected by the prospecting or mining operations to its natural or predetermined state or to a land use which conforms to the generally accepted principle of sustainable development.

The National Department of Tourism, Environment and Conservation (DTEC) and Minerals and Energy (DME) budget for funds on an annual basis for the rehabilitation of old and abandoned mines and the DME is responsible for the rehabilitation of these dumps (Nel, 2006).

1. 5 Rational /justification of the research

Despite the banning of the asbestos mining in South Africa, the effects of exposure are still experienced many years after. Un-rehabilitated mine dumps still export asbestos dust / fibers to nearest vulnerable areas. Products containing asbestos material pollute the environment and cause human health problems when they break down to fibers (SAI, 2008). The rate of developing mesothelioma condition in South Africa is the highest in the world (Kahn, 2013; Abratt *et al.*, 2002). Mining of asbestos and use in South Africa spread asbestos related diseases that have spread beyond asbestos mines.

1.6 Problem statement

A study undertaken by the Council for Geoscience (CGS, 2015) has identified more than 6000 derelict and ownerless (D&O) mine dumps in South Africa. Of these, there are over 200 D&O asbestos mine dumps across the country. Through the desktop and ground truthing studies undertaken at CGS, 45 high risk asbestos mine dumps have been identified in Limpopo, Mpumalanga and Northern Cape provinces. The high risk asbestos mine dumps exist in close proximity to vulnerable areas that includes the residential areas, water bodies, conservation areas, etc.

A significant number of these mine dumps have been rehabilitated while others have not and members of nearby communities are complaining about human health effects associated with the exposure to asbestos fibres.

Asbestos mineral is a microscopic fibrous silicate, which can be inhaled easily by those who are exposed to it, especially people in occupational settings or residential areas that are closer to the asbestos mine sources (Moja et al., 2016; USA-IM, 2006).

Some of the health effects associated with the inhalation of asbestos fine dust include the non-cancer respiratory effects (such as asbestosis), mesothelioma (a rare type of cancer of the membrane around the lungs and body cavities) and lung cancer (Phillips et al., 2012; Braun et al., 2006). Wind and rainwater are the main transport mechanisms of asbestos fibres from source to receiving areas.

Since D&O asbestos mine dumps have been abandoned by their previous owners and licence holders, the Department of Mineral Resources (DMR) is now the custodian of the dumps on behalf of the people of South Africa. Unfortunately, the previous mine owners did not save money for rehabilitation and now DMR is faced with the resulting environmental liabilities. DMR together with CGS and MINTEK are involved in minimizing the impacts from D&O asbestos mine dumps. This study will contribute develop method of monitoring and analyses, as well as provides the status of asbestos load in environmental samples around sites in Limpopo and Mpumalanga provinces.

1.7 Aim of this study

The aim of the study is to modify and apply the crude settleable dust collection and analysis method in the search for suitable asbestos analyses method.

1.7.1 The specific objectives

The specific objectives are:

- To experiment and modify parameters of the crude settleable dust test method;
- To apply the modified crude settleable method in the measure of airborne asbestos pollution;
- To test the performance of the new asbestos mineral count method;
- To validate the asbestos new mineral count method against fibre count.

1.8 Organization of thesis

Chapter One: Introduction and Background gives a brief but detailed history of mining industry in South Africa, with reference to the history of asbestos mining in Northern Cape, Limpopo and Mpumalanga Provinces, problem statement, the aims and objectives of the research as well as the organization of the thesis.

Chapter Two: Literature Review gives a detailed history on how asbestos was mined globally, regionally and nationally. The chapter gives a detailed characterization, formation and quantification of dust contaminated with asbestos, physico-chemical properties and brief description of the passive and active samplers/method used for this research, different types of designs and in previous research.

Chapter Three: Research design and methodology gives details of the research design which is divided into two phases: the fieldwork and the experimental phase. The chapter gives a detailed description of the study areas, sampling points, fieldwork and laboratory methods used for samples collection and analysis of collected samples, types of samples collected and dust monitoring units used. This also covers the passive and active samplers used for this research.

Chapter Four: Results and discussion give the results comparison of the settleable dust methods collection of settleable dust application, modified and testing their performance and selecting the most reliable and suitable method for the research, novelty of the study and settleable dust rates results.

Meteorological data such as rainfall, wind rose, wind speed, wind direction, humidity. XRF (geochemistry) results and X-ray Diffraction (XRD) mineralogical composition that differentiates the dominant mineral groups are covered. Scanning Electron Microscopy-Energy Dispersive Spectroscopy (SEM-EDS) gives the morphological information about parameters such as length, width, size, shape and type of asbestos and the mineral group of asbestos detected and XRF (geochemistry). Asbestos fibres count results from filter substrate samples from the AirCon sampler and E-sampler are discussed.

Chapter Five: Conclusion and recommendations presents the conclusion of the findings of the research on the selected method and performance and validation of the method used. The Phase Contrast Microscopy (PCM) which has been used to quantify asbestos fibres count and concentration that has been captured in different filter substrates was discussed.

List of reference: List of references used in the thesis.

List of appendixes: meteorological data, SEM-EDS data, permission letters for usage of the laboratory facilities of the Council for Geosciences, permission to use the research sites identified in Limpopo and Mpumalanga Provinces, ethical clearance letters, turnitin plagiarism report, tables showing asbestos fibre count and published front pages article.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter contains a detailed account of the history of asbestos mining globally, regionally and nationally. It also includes processes such as characterization, formation and quantification of dust contaminated with asbestos minerals. It also includes the passive and active sampling methods used in this research and previous researches. The analytical instruments used to analyse the collected samples.

2.2 Overview of asbestos mining

Asbestos is one of the oldest mineral commodities that is widely used by human beings (Nolan, Langer and Wilson, 1999). In 1860, large deposits of asbestos were found in Canada and as the search for what was then hailed as the “miracle fibre” spread wider, more deposits were also found in Russia (Povtak, 2013), Italy (Virta, 2003), in South Africa (Hart, 1988) and in Cyprus (King *et al.*, 2006).

Large-scale mining of asbestos deposits near Quebec, Canada began in 1878 and spurred the development of other commercial uses (Brady *et al.*, 1997; Kroschwitz, 1993 and Hornbostel, 1991). In 1900 asbestos was being used to make gaskets, fireproof safes, bearings, electrical wiring insulation, building materials and even filters to strain fruit juices (Bulman, 1982). Despite the commercial successes of asbestos mineral, it has also been linked to declining health conditions of those who were exposed to it (Frank and Joshi, 2014). Health problems associated with exposure to airborne asbestos particles has been noted since the early 1900s and resulted in the passing of the Asbestos Industry Regulations of 1931 in England (Virta, 2005).

In the early mid-1960s health problems began to surface among the shipyard workers who handled asbestos insulation in the United States (US) (Allenman and Mossman, 1997). The US health problems reached the crisis stage by the 1970s forcing the Environmental Protection Agency (EPA) to place restrictions on the use of asbestos (Aron and Myers, 1987).

The Environmental Protection Agency lifted the ban for certain kinds of asbestos in 1991 since the public had been made aware and manufacturers had removed asbestos from their products (Povtak, 2018).

As a results of health fears associated with exposure to asbestos minerals, its usage in the US fell from 880 000 tons/year in 1973 to less than 44 000 tons/year in 1997 (Hornbostel, 1991).

Asbestos mining operations are found in 21 countries and the leading producers of asbestos are Russia (formerly USSR), Canada, Brazil, Zimbabwe, China and South Africa (IARC, 2012). Smaller deposits are found in the US and several other countries (Brady *et al.*, 1997). Larger asbestos deposits are found in USSR where chrysotile is found and it was associated with ultrabasic and, to a small extent, with dolomite rocks (Virta, 2012). Chrysotile deposits were found in the south-central and southern Ural Mountain in the Sverdlovsk region which produced more than half of the Russian output (MI& FERS, 2010). The world leading producer of asbestos in the 1800s was the USSR where their last five year (2000-2012) plan foresaw an increase in production from about 2 Mt in 1981 to 2,22 Mt of fibre in 1985 (Hart, 1988). Asbestos occurs in the eastern and western belt of Canada. The eastern belt is the most important asbestos producing area in Canada as confirmed by serpentinised ultramafic rocks stretching from Baie Verte district of Newfoundland through the Thetford Mines, Black Lake and Asbestos district Quebec, to the Belvedere Mountains in Vermont (Kuyek, 2003). The Belt was part of lower paloezic ophiolites of the northern Appalachians; serpentine ultramafic bodies have been subjected to faulting and intense shearing, creating the environment for asbestos. The western belt is in British Columbia and forms parts of the Mississippian ultramafic bodies in the 110 km long chain of the McDame intrusives. Ultramafic rocks have been altered to serpentinite and contain chrysotile where the cassior body was regarded as commercial.

In Italy asbestos deposits are mainly found in rocks and soil where it naturally occurs. The possibility of fibre being released into the atmosphere from rocks and soil thus reaching nearby residential areas is high (Cattaneo *et al.*, 2012).

Chrysotile is mined and it is associated with antigorite, form sterite and diopside, chloride and Ti-rich magnetite present as accessory minerals (Burkhard and O'Neil, 1998). Antigorite is highly prevalent in serpentine and chrysotile veins and is associated with other fibrous polymorphs of serpentine, mainly antigorite (Cairncross, 2013). Chrysotile is still mined in other parts of the world and applied in industries for the commercial production of asbestos fibres. Amosite and crocidolite are no longer mined but are sold from the stock (Aron and Myers, 1987). The estimation is less than a few hundred metric tons (100 tons) annually using amosite and crocidolite (Case *et al.*, 2011). The products of actinolite, anthophyllite and tremolite asbestos may be still be mined in small quantities providing the product is less than hundred metric tons annually (<100 tons) (Virta, 2001).

Table 2.1 shows international asbestos production per country led by Canada with 510,000 tons, Brazil with 250,000 tons, China with 250,000 tons, Zimbabwe with 150,000 tons and the Republic of South Africa with 130,000 tons (Moel-a-Huisser, 1993).

Table 2.1: Asbestos world production by country

Country	Production (tons)
Commonwealth of independent states	1,700,00
Canada	510,000
Brazil	250,000
China	250,000
Zimbabwe	150,000
Republic of South Africa	130,000
Greece	45,000
Swaziland	30,000
India	25,000
United States	15,000
Columbia	5,000
Romania	3,000
Yugoslavia	1,000
Total	3,114,000

Figure 2.1 shows China to be the highest consumer of asbestos fibre with 26 %, followed by India with 25 % and Ukraine being the lowest asbestos consumer with 2 %.

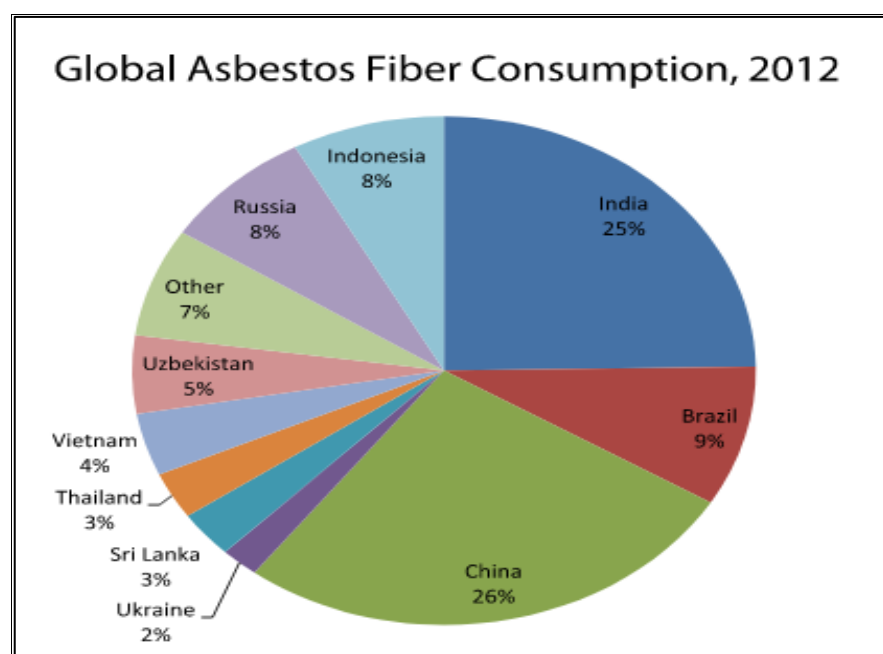


Figure 2.1: Global asbestos fibre consumption (GAFC, 2012)

Asian countries like China, India, Thailand, Vietnam and Indonesia consume about 70% of the global asbestos minerals which are mainly used to manufacture insulation, roofing and building material products, as well as car brakes (Khan *et al.*, 2013) (Figure 2.1).

2.3 Global asbestos mining experiences

China has been a dominant and consistent asbestos producer and was the largest producer in the 1950s and the second largest today (Virta, 2014). This makes China a major player in the global market of asbestos production and consumption. China represents 30.5 % of the total world asbestos consumption and was the first world consumer of asbestos (Tse, 2016). It was estimated that in the 60s and 70s, from 62 to 90 millions of tons of asbestos were produced and the mined chrysotile used commercially because of the long strength of the asbestos fibres (US Geological Survey, 1980).

A total of 310, 000 tons in 2001 to 450 000 tons in 2009 were used for industrial and urban purpose (China Asbestos Association, 2012). Some of the asbestos materials were used for cement products, sealing products, gasket products, heat-insulating products and textiles (Kazan-Allen, 2009; Dehong, 2004). The negative health effects encountered in China due to exposure to chrysotile asbestos mineral were lung cancer and gastrointestinal illness (Luo, 2003).

Asbestos mining exposure in Canada has occurred since 1899 and it resulted in negative health effects. Dust control legislation for mines was introduced in 1971 (Matsabatsa, 2009). The decreased use of asbestos in mining can be ascribed to public health issues; restrictive standards were introduced whereby the allowable level of asbestos dust fibre exposure for miners was reduced from 5 fibres/cm³ in 1971 to 1 fibre/cm³ at present (Wang *et al.*, 2013). Canada continues to be one of the leading producers of asbestos in the world with 2.4 x 10⁵ tons mined in 2003 (Freedman, 2007; Luus, 2007). The common methods used for asbestos mining are underground diggings and open cast (Anhaeusser, 2012). The asbestos material was milled and transported to the plant for sorting out into various grades. Long fibres were commercially used; short fibres were discarded, creating the current exposure of fibre which causes asbestos related diseases (Braun and Kisting, 2006). This is exacerbated by unrehabilitated asbestos mine dumps.

Current risks of exposure to asbestos create a serious problem for miners and residents living near the asbestos mines. The residents still continue to inhale dust which is contaminated with asbestos dust unknowingly. This causes abnormal functioning of the lungs resulting in lung cancer due to a rare asbestos-related disease called mesothelioma (Polissar *et al.*, 1984). The pathways of the asbestos fibre exposure is through ingestion, skin contact and inhalation (Sanchez *et al.*, 2010).

Even at lower concentrations of dust, asbestos fibre still causes significantly dangerous health effects. Most mine workers are subjected to the exposure of asbestos from 10-100 times the Canadian legal limit of 1 fibre/cm³ (Luus, 2017). The mine workers have suffered variety of asbestos related diseases (Renner, 2005, Cudgell *et al.*, 2004 and Berry *et al.*, 2000).

It has been reported that about 7,307 residents of Libby, Montana have gone through occupational and environmental exposure to amphibole asbestos from a local vermiculite mine (Pfau *et al.*, 2005). Experiments indicate that crocidolite asbestos has a slightly more toxic effect than chrysotile on the immune function of pulmonary parenchymal cells (Rosenthal *et al.*, 1998).

Asbestos has been found to be toxic to the genes of mine workers and their wives. This damages the DNA, gene transcription and protein expression and leads to inflammation, cell death and errors in modulating cell proliferation (Kamp and Weitzman, 1999; Siders, 1987).

Russia is the world's largest producer of chrysotile asbestos and about 500 000 metric tons of asbestos is gathered from the mine each year — roughly 20 % of the world's supply (Mauney, 2016). Russia's high production numbers stem from the city known as Asbestos, located about 900 miles northeast of Moscow (ATWB, 2006). It was once known as the dying city because of its high rates of mesothelioma and related diseases. Asbestos is home to a mine that measures seven miles long, one-and-a-half-miles wide and more than 1 000 feet deep (IARC, 1977). Chrysotile was mined in Russia through underground to open cast and the milling process was used to separate the asbestos fibre grade according to their strength, tensile and long or short size. Asbestos shrouds were wrapped around the dead before their bodies were tossed onto the funeral pyres used to prevent their ashes from being mixed with those of the fire itself (Kayser *et al.*, 1982).

Asbestos mining in India begun in 1973 and was closed in 2002 (Walz and Koch, 1990). Abandoned asbestos mines in India still continue to contribute to the asbestos related diseases of the residents in Roro Village (National Academy of Science, 1977).

Most people in this village are suffering from lung cancer and asbestosis and other asbestos related diseases probably due to the presence of unrehabilitated asbestos mine dumps in the area. Analyses data show soil sample from the Roro Village to be composed of 14.3 % of asbestos mineral (HSDB, 2001a).

Chrysotile was the main asbestos-form mined using both underground mining and open cast mining approaches (HSDB, 2001b). Asbestos is mainly used for manufacturing asbestos-cement sheets, asbestos-cement pipes, brake linings, clutch linings, asbestos yarn and ropes, gaskets and seals (Mauskar, 2008).

Brazil is the world's third-largest producer of asbestos, producing 307 000 metric tons in 2013. It is also the third largest exporter, shipping primarily to Asia, Mexico and Colombia (Hodgson *et al.*, 1979). Although exporting brings in a significant amount of revenue for exporters, Brazil keeps a large share of the mineral within its borders (Pacheco, 2018). The country used 181168 metric tons as recently as 2013 and it is ranked number four among the world's consumers (Ross *et al.*, 1984). Brazilian companies continue to mine asbestos and produce products with it, including SAMA and Eternit S.A. About \$1.3 billion annually was generated as product for Brazil. While these companies employ nearly 3 500 people, the industry claims that mining the toxic substance creates about 200 000 jobs (ATSDR, 2009). Estimates predict the rate of mesothelioma and related deaths will continue rising in Brazil's future. In the 1980s a pulmonologist at the University of São Paulo Medical School treated about 20 mesothelioma cases a year, and the number was slowly climbing. The majority of patients were current or former asbestos plant workers (Price *et al.*, 1998).

2.4 Southern African regional asbestos mining experience

Zimbabwe used to be the sixth biggest producer of asbestos in the world (IM & AC, 2018). Asbestos was found in the mixtures of metamorphic and intrusive or plutonic rocks, tracts known as crystalline, migmatite terranes, moderately to highly metamorphosed rocks of unknown origin with or without intrusions (Cairncross, 2000; Mugumbate *et al.*, 2001; Laubscher, 1986). The closure of the two large operating asbestos mining in Zimbabwe caused anti-asbestos lobbying.

Chrysotile asbestos mineral was mined in Zimbabwe and scientists proved that chrysotile caused cancer and other fatal diseases due to the inhalation of fibre which sticks to lung linings (WHO, 2014).

However, Zimbabwe has now secured domestic and international markets for asbestos products in Asia. Consequently, Zimbabwe has reopened Shabanie and Mashava mines in the southern Zimbabwe which resumed operation at the end of 2017 after finalisation of a \$100 million loan from the Chinese company XCMG. The two mines will create 100 000 jobs in Zimbabwe and 140 000 tons will be produced annually.

In Swaziland, the British firm Turner and Newall operated an asbestos mine in north-western Swaziland in the early 1980s (Coakley, 2001). The mine is situated in the western part of the country. Chrysotile was mined from Bulembe Mine in northern part of Swaziland between 1939 and 2000. One thousand (1 000) miners were employed before it closed in 2000. Bulembe mine town was turned into a ghost town after the mine closed. Now the town where the mine was situated has been turned into an orphanage for homeless children diagnosed with HIV/AIDS (Anahausser, 1976). Four hundred (450) former miners in Swaziland suffer from asbestos-related lung diseases.

The first discovery of asbestos minerals in South Africa was in the Northern Cape Province where crocidolite was mined in Prieska in a 400 km in length and 50 km in width belt between 1803 and 1806. The Cape Asbestos company started mining north of Prieska in 1893 and created a market in the UK for variety of fibres (Hall, 1930). After the first World War the extension of mining developed and stretched to the Botswana border as result of demand for crocidolite.

Twenty-four crocidolite mines in the Cape were small diggings controlled by distributors and farmers; these produced 7 000 tons per year. Most asbestos mining started as open cast working as underground mining and milling was labour intensive (Felix *et al.*, 1994). Before the method of hand sorting and sieving or mechanical sorting, fibre was cobbled from waste rock by handheld hammers. Underground workings extended asbestos mining to towns such as Koegas, Kuruman, Prieska and Griquatown where central mechanized mill facilities were commissioned (Hanker, 1966).

Over a hundred square kilometers of a mill was operated by means of dry and exhaust stacks and it spewed asbestos dust and led to airborne pollution across the region (Sluis-Cremer, 1965). Asbestos minerals in Limpopo Province were discovered in the north-eastern Lydenburg district with amosite being the main asbestos type (Hart, 1988).

The amosite production reached its peak in 1970, with 100 000 tons being produced and 7 000 workers being employed due to the massive orders from Japan (WHO, 2014). Japan used amosite in the manufacturing of calcium silicate insulation boards for the building industry in 1980's. However, amosite production ceased when it was not required by the Japanese government in 1988 (Furuya, 2017). The Penge mine collapsed and the demise in the market led to the closure of its mining in June 1992. Amosite lies within the Petersburg asbestos fields 45 kilometers northwest of Penge from Mafefe in the south to Bewaarskloof in the north (Campus, 2008).

The chrysotile asbestos deposits were discovered in the Msauli River Valley near Barberton in Eastern Transvaal in the Barberton district in beginning of the 19th century and became the most commercial asbestos (Anhaeusser, 2012). Arid crocidolite and amosite fields in the district were part of the mist belt and escarpment characterized by heavy rainfall. In 1915 systematic prospecting for chrysotile followed and a number of mines started shortly at Kaapsehoop and Kalkloof (Hall, 1930). Other areas where chrysotile asbestos mines were located include in Msauli, Kaapsehoop and Stella areas (Aron, 1987). Msauli area reached its peak at 110 000 tons per annum and employed 1 650 employees (Hart, 1992). About 90% of the chrysotile was exported and shipped to Taiwan, Korea and Japan in 1973.

Bulembe mine (previously known as Havelock) one kilometer across the border into Swaziland was an older operation than Msauli which chrysotile was mined. The mine is situated in the eastern part of the Mpumalanga Province. Asbestos mined at Bulembe was transported via an aerial cableway to Barberton in South Africa. Chrysotile asbestos caused malignant pleural endotheliomas (SAIMR, 1930). Mining and production methods used were crude, with the finer material being separated from the ore by hand. In some cases spades and wheelbarrow operations were run by farmers who had found deposits on their land (Felix *et al.*, 1994).

By 1819, foreign companies had withdrawn from active asbestos mining in South Africa and a long series of mergers and acquisitions for example, Finance Company (Gefco) and Msauli Asbestos, reduced the number of mines. Gefco produces the amphiboles crocidolite and amosite commonly known as blue and brown asbestos in the Western Cape and in the north-eastern Transvaal. Msauli produces chrysotile or white asbestos in the KaNgwane homeland near Barberton (Ehlers and Vorster, 1998).

Rich deposits of asbestos in South Africa were discovered during the late 1900s; however, later mine regions lost their livelihood as the industry retrenched workers (Braun and Kisting, 2006). The last asbestos mine in South Africa ceased in 2002 and it caused a major health disaster for the mine workers and surrounding people (WHO, 2014). Diseases in South Africa were due to asbestos exposure from mills from the Pietersburg fields in Penge area where polluted dust in clouds of fibres affected even children (Scheepers, 1965). South Africa is a mineral-rich country and when mining one commodity, it is likely that other minerals including asbestos will be accidentally mined (Nelson *et al.*, 2011). The country is also known to be the major producer of diamonds, gold and the leading producers of other commodities such as platinum, chrome, manganese and vanadium. It was the third largest producer of asbestos which was mined from the 1800s to 2000 (Hart, 1988). Health effects of exposure to dust has been generated by mining of gold, asbestos and coal and other commodities including diamonds. Kimberlite which is found in diamonds also contains olivine, phlogopite calcite, serpentine, dispside, monticellite, apatite perovskite and limonite (Wilson and Anhaeusser, 1998).

Peridotite and eclogite from fragments of ultramafic rocks from Kimberlite are formed under very high pressure and xenocrysts. Eclogites are susceptible to metamorphism which form both calcic amphibole rock types such as tremolite, actinolite and glaucophane asodic amphibole with a chemical makeup similar to crocidolite (Leake *et al.*, 1997). Kimberlite has been described in association with both chrysotile and amphibole asbestos fibres (primarily tremolite) (Aoki, 1972; Warner, 1971; Warner and Rienecke, 1930).

Amphibole minerals and kimberlite occurs in ultramafic rock (Wilson *et al.*, 2007). Low-silica and high magnesium and iron content often contain asbestos (Perkins *et al.*, 2008; Pan *et al.*, 2005; Anahausser, 1976). In Tak mines tremolite and actinolite asbestos fibres have been described (Davies *et al.*, 1996).

2.4 The geological make up of asbestos mining regions in South Africa

Larger asbestos minerals deposits in South Africa with crocidolite being mined in the Northern Cape Province, amosite in Limpopo Province and chrysotile in Mpumalanga Province. The geology of the three provinces differs due to changes in environmental temperature conditions in Limpopo Province.

The Limpopo province has bushveld, majestic mountains, primeval indigenous forest, unspoilt wilderness and patchworks of farmland (MYEP, 2015). The geology of the region contains the Transvaal and Chuenespoort group; carbonate rock formation (contains iron and magnesium embedded in the rocks) form part of the dolomite series in succession near the top, which is followed by carbonate rock formation (Button, 1973). Most rocks in the province belong to the Malmani SubGroup and Penge formation. The most common rocks found in the province are shale, dolomite, chert, quartzite, conglomerate, breccia and diamictite (Visser, 1989). Penge is a town situated approximately 80 km northwest of Burgersfort, in the Greater Tubatse Local Municipality and Greater Sekhukhune District Municipality.

The asbestos mines were located south of the Pietersburg asbestos fields (Sluis-Cremer, 1965) and extend in an 80 km arc from Malisdrift in the northwest to the confluence of the Olifants and Steelpoort Rivers in the south-east (Hall, 1930).

The Penge asbestos mine and village are located in the south-eastern extremities of the Pietersburg asbestos field (Pirajno *et al.*, 2011).

The Mpumalanga province's geology is composed of the Tjakaastad and Komatipoort Group and Transvaal Super Group with the sandstones, shale, murchison, greenstone belt and intrusive granite rocks being common (Ward and Wilson, 1998). Komatities often display spectacular textures of skeletal crystals (known as spinifex textures) which branch out like fern leaves.

The textures and the chemical make-up of the rocks can be deduced from Komatiites lavas which crystallized rapidly from very hot and probably water-rich molten magma (Ehlers and Vorster, 1998). The Barberton Greenstone Belt (BGB) is located in the eastern part of Mpumalanga Province, and many asbestos mines are found in the BGB (Ward and Wilson, 1998).

The Northern Cape Province's geology the area is characterised by steep to moderately steep mountains with upper to lower lying valleys. Geologically, the study area forms part of Asbestos Hills Subgroup of the Transvaal Supergroup in the Griqualand West basin containing significant amount of iron present in the Superior type - banded iron formations (Moore *et al.*, 2010 in Slade, 1930). Asbestos Hills Subgroup stretches from Prieska to the Botswana border, forming the prominent Asbestos and Kuruman Hills. In addition, Moore *et al.*, 2010 (in Slade, 1930) documented that this succession forms the upper part of the late Archean to Early Proterozoic Ghaap Group (Transvaal Supergroup) of the Griqualand West Basin.

Mpumalanga Province: Asbestos mines are situated in Nelspruit, Kaapsehoop, Malelane, Senekal, Tjakaastad, Nkomazi Game Reserve and between Badplaas and Carolina at Msauli and Rietfontein. Chrysotile asbestos was discovered in Kaapsehoop in 1905 and the processing of asbestos fibre was done by milling.

The mine started mining open pit then later started mining underground. Msauli mining started in 1942 and closed in September 2001 (Visser, 1998).

The Kaapsehoop ultramafic complex was discovered in "four deposits mined in the western addition of the Jamestown Schist Belt (Anhaeusser, 1976b; 1986b). The intrusion layer was where the four mines were industrialized (New Amianthus or Kaapsehoop Asbestos Mine, Munnik-Myburgh, Stella, Sunnyside). The Ribbon Line in the New Amianthus Mine is a spectacular 2.13 mm fibre zone and displayed 165 seams with fibre lengths varying between 1.6-12 mm. Fibre lengths in these mines are among the longest recorded in the world and ranged in places from 50-152 mm. The cross-fibre measuring 218 mm was found in places and was sought after for museum specimens.

The mines in the Kaapsehoop area have all ceased production” after yielding in excess of 222 348 t of high-grade fiber (Hart, 1988).

Between the border gates of South Africa and Swaziland two enormous chrysotile asbestos deposits were discovered in the Barberton area and located in the Msauli-Havelock Ultramafic Complexes.

In 1887 asbestos and gold were discovered on the Havelock Concession (named after Sir Arthur Havelock, then Governor of Natal), but only in 1918 did Izaak Holtzhausen rediscover the existence of asbestos exposed in the deposit. In 1939 the major fibre was managed, then exploration followed by milling (Hart, 1988).

The mine started operation as an open pit then later changed to underground mining. The mine was located in mountainous areas and it was decided to connect the mine to the railhead at Barberton area. This resulted in the construction of an aerial ropeway by Bleichert Company of Leipzig, Germany for a distance of 20.36 km across the mountains. In mid-1937 the aerial ropeway started functioning and was completed in 1939. It was constructed to carry bulk of 13.5 tons per hour in both directions and transported all the asbestos but did not carry mine workers.

The ropeway operated successfully until the Havelock Mine ceased production in 2001. The mine produced over 2 Mt of chrysotile fibre and was at one stage the second largest Archaean greenstone belt asbestos deposit in the southern hemisphere, after the Shabani Mine in Zimbabwe and, at the time, was the principal contributor to the economy of Swaziland (Hart, 1988).

In the serpentine ultramafic rocks of the Msauli Complex asbestos was discovered across the border (believed to be an extension of the Havelock Complex) and owned by a company called African Chrysotile Asbestos Mine. In 1942 C.J. Yissel and J.F. Cronje produced 148 tons of fibre from Msauli asbestos mine and the mine was located in Diepgezet valley. There was no bridge across the Komati River at the time and an aerial ropeway was constructed across the river; from there the fibre was transported by road to the railhead at Breyton, a distance of about 130 km (Hart, 1988).

Thereafter, for a distance of about 40 km the milled and blended asbestos fibre was transported over the mountains to the Barberton area. The mine was extended to four quarries; the operation changed hands on numerous occasions.

In 2001 the mine ceased after it produced about 2.5 Mt of fibre and it operated underground in a mining enterprise owned by Gencor. The mine is now abandoned with the mill and asbestos mine dumps having been demolished, rehabilitated and the village abandoned as a ghost town (Hart, 1988).

The Stolzberg complex was discovered in the Barberton greenstone belt where a number of other chrysotile asbestos deposits were revealed including three mines: Sterkspruit, Stolzberg and Doyershoek in the south-west near Badplaas. The three asbestos mines are situated in Nkomazi Game Reserve near Badplaas. From 1942 to 1959 the Stolzberg mine was the largest of the three mines and produced 38 877 tons of asbestos fibre. The Sterkspruit Mine produced 10 769 t of quality asbestos fibre from 1951 to 1963. Mining continued for a number of years afterwards, but eventually closed, and was abandoned and rehabilitated. The production in the later years was not known. The Doyershoek mine operated from 1943 to 1946 and again later from 1950 to 1955 and produced 4 190 tons of asbestos fibre (Hart, 1988).

In 1928 to the north of Badplaas Kalkloof Mine was operating and the mine was located in Kalkloof layered ultramafic complex and ceased in 1970. The mine produced more than 45 000 tons of asbestos fibre. There were minor operations of chrysotile mining in the Barberton greenstone belt but the production data are unknown.

The geological setting and the control of most of the chrysotile asbestos deposit in Kalkloof mine were described by Anhaeusser (1976c, 1986b) and Ward (1999). All the deposits were associated with layered ultramafic complexes with the principal host rocks being serpentinized dunites, harzburgites and orthopyroxenites (Visser, 1998).

Chrysotile asbestos mineral from serpentine mineral group was mined in Mpumalanga Province. Asbestos process was milling and transporting asbestos fibres across the Barberton Mountains near by; since there was no bridge, the fibres were blown into the river. The mine is now abandoned; the mill and mine dumps have been demolished and rehabilitated and the village abandoned as a ghost town. A number of other chrysotile asbestos deposits were discovered in the Barberton greenstone belt, including three mines in the Stolzberg Complex; Sterkspruit, Stolzberg, and Doyershoek in the southwest near Badplaas.

The Stolzburg mine was the largest of the three asbestos mines which operated from 1942 to 1959 and produced 38 877 tons of asbestos fibre (Ehlers and Vorster, 1998).

The Strekspruit mine produced 10 769 tons of quality asbestos fibres from 1951 to 1963. Mining continued for a number of years afterwards, but the mine was eventually closed, abandoned and rehabilitated. The production in the later years was not known. The Doyershoek mine operated from 1943 to 1946 and again later from 1950 to 1955 and produced 4 190 tons of fibre (Anahausser, 1976).

Limpopo Province: Asbestos mines are situated in Ga-Mafefe, Penge and Burgersfort in Limpopo Province. The rocks underlying all sites in Limpopo form part of the Chuniespoort Group and consist predominantly of carbonate rocks (it was known in the past as the dolomite series). In the North Eastern Transvaal, East of Chuniespoort (where the sites are located), banded iron formation appears in succession near the top and is followed by more carbonate rocks (Visser, 1989). Minor scale asbestos mining began in Penge in 1914 and it was estimated that by 1949 there were approximately 23 very dusty asbestos mills in the Penge area (Anon, 1953). Asbestos mine dumps were formed by waste rock and waste materials from the mills during the mining period.

There were site buildings and residential quarters constructed for mine workers. In 1962 a survey conducted by the Pneumoconiosis Research Unit (PRU) concluded that everyone who lived in the area was at risk from asbestos contamination although some had no industrial asbestos exposure (PRU, 1963). The mining company Griqualand Exploration and Finance Company Ltd (GEFCO) started rehabilitation of asbestos mine dumps in 1986 until closure of the mine in 1992. Following closure of the mine, approximately 250 houses and other buildings previously belonging to the mine were used by local people and former mine employees for residential purposes (Donohue, 2007).

As the asbestos fibres are microscopic and cannot be seen by the naked eye. When the tiny asbestos fibres are released into the environment during asbestos mining processes, they contaminate the air and the soil. Asbestos fibres can travel long distances in the air before settling on the ground, thus contaminating areas far away from the source (Kwata, 2016). The fibres do not absorb into the soil instead they settle on top of the soil, where it can easily be disturbed and redistributed into the air (Hart, 1988).

Northern Cape Province: The Asbestos Mountains are a range of hills in the Northern Cape province of South Africa, stretching south-southwest from Kuruman, where the range is known as the Kuruman Hills, to Prieska. The range lies about 150 km west of Kimberley and rises from the Ghaap Plateau. The mountains were named for the asbestos which was mined in the 20th century and the latter is found as a variety of amphibole called crocidolite. Veins occur in slaty rocks, and are associated with jaspers and quartzites rich in magnetite and brown iron-ore. Geologically it belongs to the Griquatown series. The Griquas, for whom Griquatown was named, were a Khoikhoi people who in 1800 were led by a freed slave, Adam Kok, from Piketberg in the western Cape to the foothills of the Asbestos Mountains where they settled at a place called Klaarwater (Campbell, 1816).

Hardcastle lies in a scenic valley not above three miles in circumference surrounded by the Asbestos Mountains of diversified shapes. There are four long passes between the mountains, leading from it in different directions, which, not only increase the convenience of the situation, but add greatly to the grandeur of the prospect around (Campbell, 1977).

The asbestos rocks are found plenty between strata of rocks. With a little beating, the rocks become Prussian blue; others are golden, white, and brown and green (Campbell, 1816). The land was known to the ancients in the days of imperial Rome; many a mercantile pilgrimage would have been made to the Asbestos Mountains in Griqualand.

Asbestos was used in women's gowns with the added advantage of being fire resistant. Serious mining of crocidolite in these mountains started in 1893 when open-cast quarrying produced 100 tons of material (Hart, 1988).

By 1918 underground mining had started and scattered mines were to be found from Prieska to Kuruman along the length of the range, and mills were constructed at both of these towns. Between 1950 and 1960 production had risen to 100 000 tons; each mine was doing its own milling and the tailings dumps had grown in size (Hall, 1930).

The Green Mountains, for which Vermont in the US was named, were produced by the same geologic processes that produced the Asbestos Mountains - they produced an abundance of serpentine, which is the source of chrysotile asbestos (Campbell, 1816). During the mining process, asbestos would regularly go airborne and spread to nearby towns.

When people inhaled the dust, they experienced what is known as environmental exposure. One field study conducted from 1960 to 1962 in the Northern Cape cities of Prieska, Kuruman and Koegas confirmed that people living in proximity to these mines and mills faced risks of contracting asbestosis, a noncancerous asbestos-related disease (Fleix *et al.*, 1994).

High number of cases with mesothelioma of the pleura had been discovered among people who have lived in the Northern Cape and there was evidence that this condition was associated with exposure to non-industrial asbestos dust inhalation. Asbestos has heavily contaminated many parts of South Africa, most notably the Northern Cape Province. One report on the town of Penge concluded that ongoing risks of environmental exposure have rendered the area unfit for habitation. Even with the last asbestos mine closed, the Northern Cape still struggles with exposure risks from the region's 82 remaining asbestos mine dumps (Anahausser, 1976).

Gauteng Province: Asbestos mines are situated in Muldersdrift on the way to Krugersdorp and in the West Rand. Honingklip is a farm situated approximately 10 km north of Krugersdorp, in the Mogale Municipality of the Gauteng Province of South Africa. Asbestos was mined in the Muldersdrift ultramafic complex which contains chrysotile asbestos mineralization associated with serpentine dunites. The developments are progressively expanding in this formerly asbestos mining area and the site is unrehabilitated. Gelden asbestos mine operated in the early 1930 and was situated in the Honingklip mine farm (D&O Database, 2013).

The white asbestos mineral (chrysotile) was mined in the serpentine rocks of the Archaean system. Mining operation in this area was short lived and mining ceased before 1930. This former asbestos mining area has now developed into an estate called artificial dam (D&O Database, 2015). West Rand asbestos mine is situated in the West Rand area and asbestos mine dumps are close to the local communities. There are combustion gases coming out from the mine which affect local communities (coal).

North-West Province: Pomfret asbestos mine, a previously rehabilitated mine dump, is now open and chrysotile asbestos fibres have been exposed just next to the road which the community uses.

An open inclined shaft was observed on the site, where a young boy unfortunately lost his life when swimming inside the shaft, as when it rains, the shaft gets filled with water. A huge nine story old infrastructure was observed on the site, with many other old infrastructures being observed as well (D&O database, 2013).

Kwa-Zulu Natal Province: Asbestos mines in Kwa-Zulu Natal Province are situated in Fort Yolland Village. This was a small operation with an adit cut along the length of the hill, approximately 30 m in length, 5 m in width, and 3 m in depth. The mine site is close to a village (approx. 5 km) and it is frequented by people and livestock, although it is on a slope which is difficult to climb. Most materials from the hole are covered by grass and the surrounding is highly vegetated, which counters the possibility of further erosion of the slope. The mine site is situated close to a sugarcane field, and it is visible from a major road (which is within 200 m) (D & O Database, 2014).

Most holes on the site are open, and the deep holes may have been closed (as there are rocks deliberately placed which suggest that some kind of rehabilitation had taken place). In the past there were some attempts to close the holes with rocks and stabilise the slope. There was an opencast hole on top of the hill, which measures approximately 50 x 60 m in area. There was evidence of erosion material and some grass has starting to grow and to cover the exposed rock. Klipriver asbestos mine is situated where there is evidence of excavation and mine waste dumps on the hills close to local communities.

The mine is accessible through footpaths and goats pass next to the mine dump daily. There is a clear visible termite asbestos mineral fibre in the surroundings and on the surface. Another asbestos mine, namely Ntulwane, is situated close to a sugarcane field, and it is visible from a major road (which is within 200 m). Most holes on the site are open; deep holes may have been closed (as there are rocks deliberately placed which suggests that some kind of rehabilitation had taken place) to stabilise the slope.

An opencast hole on top of the hill measures approximately 50 x 60 m in area. Sithilo asbestos mine is situated some few kilometres from the local communities and there is a deep adit accessible pathway where people and animals pass daily (D&O Database, 2016).

There is clearly visible asbestos ore scattered on the hill. Other asbestos mines were Lilani and Madegela which indicate a dangerous deep adit a few metres from the road frequented by people as a pathway daily. Some waste rock dumps are in the fenced-off grazing camp near the mine adit and there is no evidence of the new fibres entering the environment.

Lilani asbestos mine is situated next to the hot spring and asbestos mines, which were more like prospecting holes, have been closed; the people in the area remember that the small operations of asbestos/mica prospecting in the area which they claim ceased around 1989. On top of the mountain top – overlooking the Lillani village are some diggings, which are closed and covered by thick overgrowth. In the vicinity to the mine there is a hot springs which attracts tourists to the area (D&O Database, 2013).

2.4.1 Previous research conducted in South Africa and outside South Africa investigating asbestos exposures and environmental contamination

A study done by Nelson et al., 2011 where SEM-EDS and PCM techniques were used for the analysis of the samples collected from tailings and mine workers lungs who are ceased were used. The results shows that even they were mining diamond asbestos mineral was accidental exposed. Ndlovu et al, 2013 the study shows that not only people worked at the asbestos mining industry also those who didn't work at the mines were affected by the asbestos fibres. The methodology used for this study was review of compensation database which employed cross sectional passive surveillance .Crocidolite and amosite asbestos fibre infected people were highly reported cases. White et al., 2008 the method used for the study was review literature on published articles and health effects cases reported in South Africa. The purpose was to determine the overall risk if environmental mesothelioma and reports of South African National cancer registry. These reports were on cases of the people who worked in the asbestos mining industry were white females, black and colores and children were affected by the exposed crocidolite fibres and other sources of exposure was asbestos mine tailings . Amosite and crocidolite fibres were identified which contribute to the health effects and other sources were due to milling and mining which is another sources of exposure of asbestos fibres. Both amosite and crocidolite fibres have been linked to environmental mesothelioma and they represent risk to human health.

According to Moja et al., 2016 ; Kwata et al., 2016 ; 2017 and 2018 where XRF,XRD and SEM-EDS, PCM techniques were used from different environmental samples(filtered dust, trapped dust, filter substrates, trapped dust, surface dust and filter cassette samples they all show the presence of asbestos mineral. Driece et al., 2010 the methodology used for the study was collection of samples which affected asbestos mineral such as plant and soil samples .The statics and risk assessments tools were used to interpret the results for the collected data and soil samples. About 60% asbestos mineral was identified from asbestos waste material at the surface and 67% on dirt roads or yards daily used by inhabitants.

Seventy seven percentage (77 %) of asbestos samples contained chrysotile and amosite mineral. All the asbestos fibres counted there were below 2000 f/m³ (> 75 µm) and reported environmental concentrations pf 1000 to 450 f/m³ (> 5 µm) from 4 -8 hours measurements.

Luo et al., 2015 in this study method used was review all the cardiovascular published articles and reports to determine what exposure of asbestos contribute to the human health. The data was retrieved from PubMed database and meta analysis was used for the data collected. The results shows that asbestos exposure could increase the risk of cardiovascular related disease mortality amongst workers from the mines as compared with from mining and cement production. Samples collected from mines who is the presences of crocidolite including the oxidant activity and cell toxicity.

Campopiano et al., 2009 the study methodology samples were collected from house roofs and using air sampler to collected airborne samples. The samples were analysed using SEM-EDS techniques were samples were coated with carbonate before the analysis can commenced. Amosite was detected from the roof samples and airborne samples with grid mouted filter cassette. Cement roof and asbestos cement are detected which is great concern for the local residents.

2.5 The consequences of asbestos mining

South Africa has a long history of mining and exporting asbestos, a toxic mineral fibre linked to the rare and aggressive cancer mesothelioma and various other diseases (Abratt *et al.*, 2002). Although South Africa has banned the use, processing and manufacturing of asbestos-containing products in 2008, it has managed to mine three asbestos minerals on a large scale: amosite, chrysotile and crocidolite (SAI, 2008). While South Africa has used asbestos domestically for a variety of different purposes, the vast majority of its mined reserves were exported to other countries (Moja *et al.*, 2016).

Asbestos's natural resistance to heat, chemicals, acid and electricity made it a highly desirable material that served a wide range of uses. Asbestos had more than 3 000 documented uses. However, manufacturers primarily used the mineral for insulation and fireproofing applications (SAI, 2008).

In South Africa and worldwide, asbestos was once a popular material and used to manufacture products like cement building material, water and sewage pipes, floor tiles and coverings, roofing and other construction materials, textiles, brakes, gaskets and clutch pads (USEPA, 2008).

The asbestos fibre uses for industrial application include sound insulation, inflammability, matrix reinforcement (cement, plastic and resins); friction materials, chemical inertia (except in acid); fabrication of papers and felts for flooring and wrapping (Bernard, 1990).

2.5.1 Decommissioning of infrastructure and decontamination of former asbestos mining areas

In South Africa asbestos mining was banned in 2002 and regulations were put in place to prohibit the use, manufacture, importation and exportation of asbestos and asbestos-containing materials (Naidoo, 2008). The South African government in 2004 announced its plan to phase-out the use of asbestos by 2009 and the announcement triggered confusion in neighbouring Zimbabwe, which at the time was a major importer of chrysotile. Between 2004 to 2006, Zimbabwe urged for a change of heart on the ban asbestos proposals, by indicating that chrysotile fibre has a different structure and chemical composition, and that it is not a health or environmental risk (Kazan-Allen, 2006). The banning of asbestos in South Africa had an unpredictable effect on its export earnings: South African exports earned Turnall Fibre and Cement company R 22 million in 2007 from the leading asbestos manufacturer in Zimbabwe (Naidoo, 2008). On March 28, 2008 the Department of Environmental Affairs and Tourism (DEAT) gazetted the asbestos banning regulations.

The import or export of asbestos or asbestos containing materials, excluding material in transit through the country, and the acquisition, processing or repackaging of asbestos and the manufacturing or distribution of asbestos are prohibited by the legislation (Holman, 2008). The legislation focused on the effort to discontinue “the use of asbestos, but it did not resolve the vast environmental contamination or the problem of existing asbestos still found all over South Africa (Holman, 2008).

The South Africa government agreed not to hold Cape PCC liable for the clean-up of former sites as part of the Cape PPC case in 2001, however, certain conditions had to be met before any money would be distributed. The South African Government (specifically the DMRE) became responsible for the rehabilitation of abandoned and ownerless asbestos mines with the implementation of the law (MPRD Act 28, 2002).

According to the NEMA's (no.107 of 1998), financial regulations and the final rehabilitation, decommissioning and mine closure plan forms a component of the environmental management programme to be submitted in terms of Section 24N of the Act and the Environmental Impact Assessment Regulations (2014) and will be subjected to the same requirements of the environmental management programme with regard to opportunities for stakeholder review and comment as well as auditing.

The objectives of this final rehabilitation, decommissioning and mine closure plan is to identify post-mining land use that is feasible through:

- providing the vision (goals), objectives, targets and criteria for final rehabilitation, decommissioning and closure of the project;
- outlining the design principles for closure;
- explaining the risk assessment approach and outcomes and link closure activities to risk rehabilitation;
- detailing the closure actions that clearly indicate the measures that will be taken to mitigate and/or manage identified risks and describing the nature of residual risks that will need to be monitored and managed post closure;
- committing to a schedule, budget, roles and responsibilities for final rehabilitation, decommissioning and closure of each relevant activity or item of infrastructure;
- identifying knowledge gaps and how these will be addressed and filled;
- detailing the full closure costs for the life of project at increasing levels of accuracy as the project develops and approaches closure in line with the final land use proposed; and
- outlining monitoring, auditing and reporting requirements.

2.5.2 Filling of open shafts or holes

Most asbestos mine open shafts or holes are vertical and inclined shafts. The width of the asbestos open shafts ranges from 100 m to 500 m. It is easy for livestock and wildlife to get trapped in the open vertical shafts and holes.

In the horizontal open shafts or holes, the height ranges from 10 m to 50 m. It is important to seal the open vertical shafts or holes to reduce physical damage and loss of human life.



Figure 2.2: Asbestos horizontal, vertical and inclined shafts

2.5.3 Rehabilitating subsidence areas

The occurrences on the unstable subsidence areas are in dolomitic areas such as Centurion and some part of Johannesburg where underground mining took place in the 18th century. The areas are stabilized by the pillars which support these unstable areas but during earthquakes, sinkholes emerge due to the instability of the land/areas. Rehabilitating subsidence areas such as sinkholes is a challenge because of instability during earthquakes (White, 2013).

2.5.4 Rehabilitation of asbestos mine dumps

Waste rock and tailings are mining waste on land surfaces, which often pose highly stressful conditions for rehabilitation (Li, 2006). The abandoned mine tailings have highly varied physical, chemical and ecological conditions.

Mine tailings are normally inconstant in physical composition regarding depth and low in organic matter and vital plant nutrients which impede the establishment of vegetation (Hossner and Hons, 1992). Mining activities disturbed the rehabilitation sites with the target to achieve the return of a disturbed site to a degree of its former state or to a sustainable usable condition; This emphasizes the reparation of ecosystem processes, productivity and services (SER, 2004).

The rehabilitated condition will most probably not achieve the original condition and land use of the impacted area (Mulligan, 1997). Section 38 (1) of the MPRDA (Act no 28 of 2002) refers to having the mine area restored to its natural or predetermined state, but this is tempered by the qualification that rehabilitation must be practicable and also provides for the Public Participation Process to define end use. Internationally, there are three schools of thought regarding the objectives of rehabilitation. These are as follows (Coaltech, 2007):

- What the affected community wants, the affected human settlements gets:
the key focus is on providing the end product requested by the affected human settlements, rather than on the previous status quo;
- Restoration of previous land use capability: the original thought process in the South African context, because mining often occurs on land with high agricultural potential; and.
- No net loss of biodiversity: there must be no loss of biodiversity and rehabilitation must restore the biodiversity of the site to its natural state.

The rehabilitation objective ordinarily covers elements of the three approaches in the South African context. Rehabilitation objectives must be aligned with the national and regional Integrated Development Plans (IDPs), which may or may not match the local community's wishes (Coaltech, 2007).

2.5.5 Formation of asbestos mine dumps waste

Mine dumps associated with gold and other commodities are formed through the accumulation of waste emanating from the mining sites (Yalala, 2015). In the case of asbestos dumps, they are formed in the same way explained, especially through accumulation of short unwanted asbestos fibres that are discarded together with other type of waste. The manufacturing sector preferred and used only long fibres (Campopiano *et al.*, 2009).

Mine waste dumps differ in size, physico-chemical composition and behave as secondary sources of dust pollution if not rehabilitated. Common sources of transport of surface contaminated dust from mine dumps to nearby vulnerable areas are wind and rain water (Oguntoke *et al.*, 2013).

- Soil depth

The establishment of self-sustaining vegetation involves the rehabilitation process in most cases of rehabilitation, as in asbestos rehabilitation. The surface zone of the rehabilitated landscape should be replaced by soil, excavation of overburden or processing of mineral waste to support the plant growth (Mulligan, 1997). The factors that should be taken into consideration during post-mining land use are the quantity and quality of the surface, subsoil available and the underlying nature of the waste material for the depth of soil replaced on excavated overburden or tailings governed. To prevent secondary pollution due to the health risks associated with asbestos, the dumps have to be sufficiently covered by topsoil. A layer of soil as thin as 50 mm will aid in the vegetation establishment by providing a suitable environment for seed germination by allowing infiltration of water and supplying nutrients and microorganisms if the underlying material does not have major limitations to root growth, such as salinity, sodicity or acidity (Mulligan, 1997).

- Chemical properties of tailings

The adequate nutrient supply, a favourable pH, the absence of toxic elements and a low salinity are the major chemical properties affecting rehabilitation of asbestos dumps. For satisfactory plant growth, the root zone must be characterised by the following:

Adequate nutrient supply: A lack of one or more of the essential nutrients is the most limiting factor to plant growth on mine wastes. Deficiencies of nutrients in overburden waste or dumps are easily rectified with the addition of fertilizer (Mulligan, 1997). Nitrogen (N) is a limiting factor in most dumps. Many tailings are deficient in Potassium (P) and are commonly deficient in Sodium (K) (Hoosier and Hons, 1992).

Excess or deficiencies in Mo, Calcium (Ca), Potassium (P) and Nitrogen (N) are the key factors responsible for poor plant growth in asbestos dumps where there is moisture stress (Van Rensburg and Pistorius, 1998).

To balance the Ca: Mg ratio and increase the long-term success of re-vegetation, the application of gypsum can be made to asbestos dumps.

A favourable pH: Due to Aluminum(Al) and/or Manganese (Mn) toxicity, above 9.0 as a result of immobilisation of Potassium (P) and micronutrients such as Iron (Fe), Copper (Cu), Zinc (Zn) and Manganese (Mn), the optimum pH range for vegetation establishment varies, but little growth occurs at pH values less than 4.0 (Mulligan, 1997).

An absence of toxic elements: High pH values and available heavy metal concentrations in the dumps are larger than the normal limits which plants can tolerate for growth on the asbestos dumps (Ellerly and Walker, 1986; Mulligan, 1997). Under different pH conditions metal toxicities can occur in waste rock and dumps. The solubility can be reduced by liming to raise the pH or by adding Potassium ("P") fertiliser or by incorporating organic matter to complex the metametals when toxic metal occur (Mulligan, 1997). The presence of heavy metals decrease root respiration, water and nutrient uptake, and inhibit cell mitosis in root meristematic regions. The microbial and microfaunal populations in the soils may also be reduced by the presence of heavy metals (Hossner and Hons, 1992).

Therefore, the determinants of the degree of toxicity of a soil for plant growth include clay and organic matter contents, cation exchange capacity (CEC), pH, and the concentrations of Ca and P soil properties which affect the proportion of metal which is either in solution or exchangeable.

Low salinity: In many dumps materials' excess concentrations of soluble salts are present. Clay dispersion and a reduction in electrolyte content through leaching results when there are high levels of Na. One of the main limitations of vegetation establishment on open-cast mines and asbestos dumps is because of the salinity which causes surface crusting (Mulligan, 1997).

2.5.6 Physical features of the asbestos mine dumps

A suitable root zone, solar radiation, texture of the tailings/dumps, erosion, water runoff and secondary pollution are the major physical properties affecting rehabilitation of asbestos dumps:

A suitable root zone: A good available water capacity and sufficient drained soil provides a suitable root zone for plant growth. The growth medium should not cause mechanical impedance to the expanding root system. There are functions and conditions for the pore size distribution in the medium and its stability for the suitable zone to plant growth. Bulk densities of mine dumps are sometimes elevated due to compaction. Limited rooting volumes generally become a problem for root penetration and moisture stress (Hossner and Hons, 1992).

Solar radiation: Dumps exposed to direct solar radiation can have extremely high temperatures of up to 65°C. High potential evapotranspiration and low water-holding capacity suggest that water deficit" limits re-vegetation of coarser dumps, especially in arid regions (Hossner and Hons, 1992).

Texture: The composition of the original material, stratification and the method of slurry entry into the dump's pond depends on the texture of the dump's ranges from sand to clay. Where there is a high bulk density resulting in low infiltration and permeability and restricted root penetration due to poor structural characteristics, fine-textured, non-aggregating materials tend to pack.

The coarse textured materials are generally poorly buffered, devoid of organic matter, deficient in nutrients, without structure, prone to crusting, and have a low water-holding capacity (Hossner and Hons, 1992; Mulligan, 1997).

The common characteristics of mine dumps are brought about by differences in texture, lack of organic matter and variable mineralogy due to crusting, cracking and a general lack of structures (Hossner and Hons, 1992).

- Microbiological properties of dumps

The accurate assessment of microbial human settlements function and structure and the significance of microbial human settlements in sustainable soil ecosystems have been acknowledged for some time and are an essential element for evaluating impacts of management practices (Tate and Rogers, 2002). The microbial biomass accounts for only 1 – 3 % of soil organic carbon, but it is the eye of the needle through which all organic material that enters soil must pass according to Jenkinson (1977) and Morris *et al.* (2003).

The long-term sustainability of ecosystems is measured by adding to the collection of information on soil status that will serve as an indication of soil quality and analysis of soil microbial properties needed to promote plant growth (Ibekwe *et al.*, 2002). Five criteria against which the potential of the restoration of a particular ecosystem could be judged include:

- It must be relevant to the ecosystems under study and to the objectives of the assessment programmes;
- It must be sensitive to anthropogenic changes;
- It must be provide a response that can be differentiated from natural variation;
- It must be environmentally being;
- It must be cost effective to measure (Harris, 2003).

Cultivation-dependent techniques and cultivation-independent human settlements profiling are some of the methods used to investigate soil micro-organisms. The methods can be divided into the biochemical, physiological and molecular approaches. It has been estimated that less than 0.1 % of the micro-organisms found in typical soil environments are cultivable using modern culture media formulations (Hill *et al.*, 2000).

In recent years a culture-based method has emerged to characterise soil microbial human settlements, including a range of methods with distinct advantages over those previously used. Polymerase chain reaction amplification includes analysis of enzymatic activities, phospholipids fatty acid (PLFA) analysis, human settlements level physiological profiling and nucleic acid based techniques.

The fundamental functioning of soil ecosystems and the assay of a variety of soil enzymes give an indication of the diversity of functions that can be assumed by the microbial community when referring to microbial activity (Claassens, 2008). Both valuable indicators of the status of the system and the effectiveness of management interventions were obtained from analyses of microbial community function (Harris, 2009). Under optimization, reaction conditions indicate the potential of enzymatic activity in soil samples for enzyme assays which were performed (Tate and Rogers, 2002).

The advantage of standardising environmental factors allows for comparison from different geographical locations and environmental conditions, rather than assaying actual enzymatic activity through the use of buffered and optimised methods (Claassens, 2008). The accurate measurement of oxidative capacity of the soils is therefore called viable micro-organisms through the presence of dehydrogenase in all micro-organisms. The dehydrogenase assay can provide a valid indication of soil microbial activity because it depends on the metabolic state of soil micro-organisms and could be valuable in ecological investigations according to Smith and Pugh (1979). The application “to estimate the degree of recovery of the dumps and mine removal in semi-arid regions are the measures of dehydrogenase activity (Claassens, 2007).

-Flora and Fauna

The establishment of early vegetation on the dumps in order to reduce the risk of degradation of the artificial system created is the main objective of rehabilitation. Therefore to reduce soil movement to a minimum is the primary objective of re-vegetation. The re-vegetation aims are:

- To minimize erosion and stabilise the soil;
- To prevent contamination of streams and air by particulate matter;

- To re-establish nutrient cycles;
- To enhance soil physical properties; and
- In the longer term, to re-establish naturally sustaining native plant ecosystems (Coaltech, 2007).

The key indicator of successful rehabilitation is re-vegetation and reflects the critical stages of ecosystem development and functionality. Both natural and man-made landscapes determined by optimum vegetation cover thresholds that ensure the biological control of hydrological processes has been stressed as an important goal for the rehabilitation (Moreno-de las Heras *et al.*, 2009).

Climatic restrictions severely constrain the development of continuous vegetation cover as is the case in South Africa and, in particular, the areas of importance to this study. The climatic conditions characteristic of the arid and semi-arid areas of southern Africa create difficulties with the determination of the establishment of permanent self-sustaining vegetation cover. The elevated topography of dumps and mine stockpiles are accompanied by difficulties due to soil erosion (Milton, 2001). The reduction of the energy of runoff stimulates the stabilisation of soil by forming soil aggregates and vegetation cover is effective in reducing surface erosion because the roots bind the substrate (Moreno-de las Heras *et al.*, 2009). This reduces the concentration of heavy metals entering watercourses as well as the visual scars of the mining operations.

Further, vegetation cover can return a large proportion of percolating water to the atmosphere through transpiration (Tordoff *et al.*, 2000). In order to meet re-vegetation objective the uses of post-closure land requires an agreement with the landscape planner for each site.

In association with the end-user for human settlements, vegetation and faunal requirements have been set for the Public Participation Process. This includes the re-establishment of the native vegetation, erosion control for the protection of water resources, establishment of high quality grazing or the preparation of lands for arable use.

The species designated for rehabilitation establishment should provide protection from erosion and meet the biodiversity objectives. The rehabilitation success is recorded on the basis of vegetation establishment and its composition (Coaltech, 2007). It is critically important to use species that are locally adapted to the area (Morgental *et al.*, 2004). Monitoring of mine site rehabilitation is another useful indicator for habitat complexity, which is the mix of plant life forms and other structural features that provide suitable habitats for animals.

Based on the ecological principle that more habitats for animals will develop as vegetation complexity and landscape integrity increase, the habitat complexity index is a simple landscape structure metric (Ludwig *et al.*, 2003). A strong correlation between habitat complexity and the abundance of different ground dwelling mammals have been demonstrated by studies conducted in Australia.

The post-mining environment provides an indication of whether the ecosystem development processes are heading in the right direction of fauna plantation as important component of native ecosystems (Mulligan, 1997). At regular intervals small mammal surveys have been conducted by setting traps in grids across the sites and checking the traps.

2.6 Health and environmental effects of asbestos mine dump waste

During the mining process, a cloud of toxic dust such as asbestos fibres is released into the air which is regularly airborne and spread to nearby human settlements. When people inhale the dust, they experience what is known as environmental exposure (Kahn, 2013).

It was not only those miners who faced an elevated risk of developing mesothelioma and other respiratory illnesses later in life, but also miners of gold, diamonds and other minerals. Because the deadly mineral can form alongside a variety of underground mineral deposits, miners sometimes disturb these deposits and suffer dangerous exposures (Nelson *et al.*, 2011) (Table 2.2).

Four main types of asbestos exposure:

- a) Mining – miners and millers, especially blue asbestos.
- b) Manufacturing – asbestos cement products and installers of insulation.

c) Maintenance workers – plumbers, carpenters, electricians who need to clear the asbestos away or drill or saw through asbestos containing materials in doing their work.

d) Environmental - the myriad situations in which asbestos fibres pollute and contaminate the environment, exposing people unknowingly and incidentally. This can occur indoors or outdoors (ART and KRT, 2009).

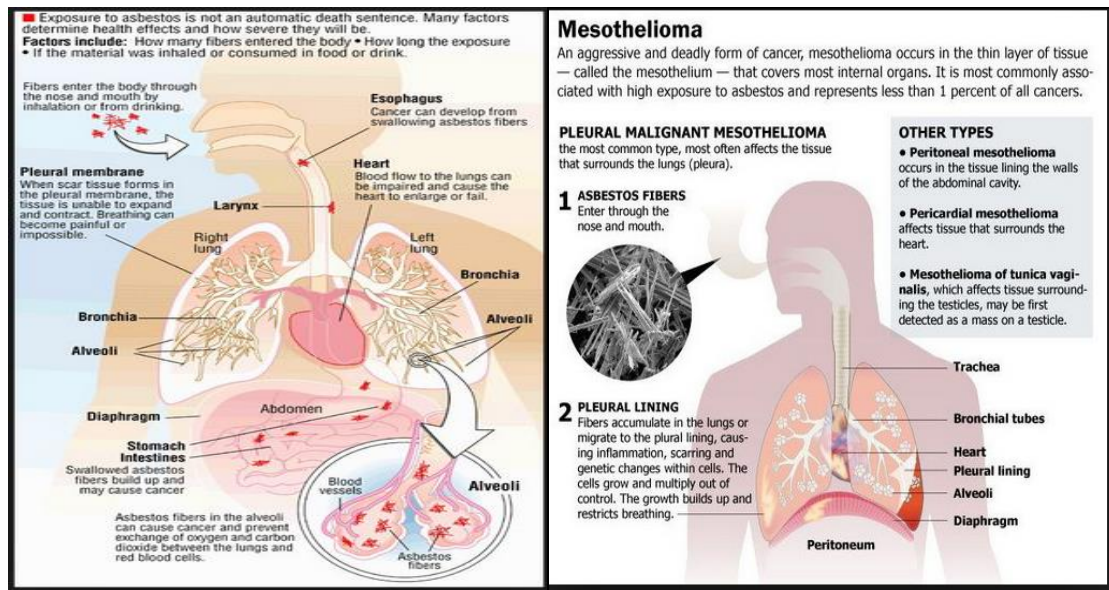
Table 2.2: A summary of the people who are exposed to asbestos (ART and KRT, 2009)

Workers are exposed	Residents are exposed	Consumers are exposed
Asbestos cement product manufacture; mining and milling; repair power stations; brakes and clutches repair, welders, ship construction and repair, textile manufacturer.	Those who lived at or near asbestos mines and mills, and their families were exposed. Many residents in former asbestos mining areas are still exposed.	Asbestos cement roofing, guttering, downpipes, water-tanks, garden products, pottery kilns and domestic heaters all contain asbestos.

People may be exposed to asbestos in their workplace, their communities, or their homes. If products containing asbestos are disturbed, tiny asbestos fibres are released into the air. When asbestos fibres are breathed in, they may get trapped in the lungs and remain there for a long time. Over time, these fibres can accumulate and cause scarring and inflammation, which can affect breathing and lead to serious health problems (ATSDR, 2009).

2.6.1 Health exposure pathways to asbestos

Asbestos fibres enter the body through inhalation (CSMI, 2008). After fibres enter the body, they can become lodged in organs and body cavities, causing inflammation or infection. Over time, this can lead to the development of serious asbestos-related illnesses (Kahn, 2013). Figure 2.3 depicts fibres that affect the lining of the lungs, abdomen and heart. If fibres become lodged in the mesothelial membrane that surrounds these areas, they can cause cells to become cancerous, resulting in the development of mesothelioma (Abratt *et al.*, 2002).



(a)

(b)

Figure 2.3: (a) Fibre that affect the lining of the lungs, abdomen and heart (b) mesothelioma development due to asbestos fibre inhalation (Google, 2018)

Asbestos has been classified as a known human carcinogen (a substance that causes cancer) by the US Department of Health and Human Services, the EPA, and the International Agency for Research on Cancer (US EPA, 2009, NTP, 2005; US EPA, 1984). Studies have shown that exposure to asbestos may increase the risk of lung cancer and mesothelioma (a relatively rare cancer of the thin membranes that line the chest and abdomen).

Although rare, mesothelioma is the most common form of cancer associated with asbestos exposure. In addition to lung cancer and mesothelioma, some studies have suggested an association between asbestos exposure and gastrointestinal and colorectal cancers, as well as an elevated risk for cancers of the throat, kidney, esophagus, and gallbladder. However, the evidence is inconclusive (Ulrich *et al.*, 2004).

Asbestos exposure may also increase the risk of asbestosis (an inflammatory condition affecting the lungs that can cause shortness of breath, coughing, and permanent lung damage) and other nonmalignant lung and pleural disorders, including pleural plaques (changes in the membranes surrounding the lung), pleural thickening, and benign pleural effusions (abnormal collections of fluid between the thin layers of tissue lining the lungs and the wall of the chest cavity).

Although pleural plaques are not precursors to lung cancer, evidence suggests that people with pleural disease caused by exposure to asbestos may be at increased risk for lung cancer (O'Reilly *et al.*, 2007). Significant exposure to any type of asbestos will increase the risk of lung cancer, mesothelioma and nonmalignant lung and pleural disorders, including asbestosis, pleural plaques, pleural thickening, and pleural effusions (ATS, 1990).

Diseases from asbestos exposure take a long time to develop. Most cases of lung cancer or asbestosis in asbestos workers occur fifteen (15) or more years after initial exposure to asbestos. Tobacco smokers who have been exposed to asbestos have a far greater-than-additive risk for lung cancer than do nonsmokers who have been exposed, meaning the risk is greater than the individual risks from asbestos and smoking added together.

The time between diagnosis of mesothelioma and the time of initial occupational exposure to asbestos commonly has been 30 years or more. Cases of mesotheliomas have been reported after household exposure of family members of asbestos workers and in individuals without occupational exposure who live close to asbestos mines (IARC, 1977).

Pneumoconiosis occurs due to exposure of chrysotile mining and milling. Mesothelioma is due to dust levels and it is associated with exposure of high dust levels through inhalation, absorption and indigestion. Amosite asbestos causes carcinoma of the lung (lung cancer).

2.6.2 Management of asbestos mine dump waste

The priority sites were selected for rehabilitation by the DMR on the basis of the type of asbestos fibre present, their proximity to human settlements, pollution vectors and the dump size. Asbestos mining ceased in South Africa many years ago, but many open asbestos mining sites remain in the country and they remain significant point sources of asbestos pollution in the former mining (Cornelissen, 2010).

Abandoned and unrehabilitated asbestos mines and dumps contain significant amounts of asbestos fibres and the former use of asbestos-containing waste rock for road and building construction pose risks to the local communities.

The rehabilitation contract document states that the following items should be provided for the commencement of the rehabilitation: clearance of bushes to create road access the asbestos dumps, employment of local communities, purchase of topsoil, seed so that grass can grow to cover the dump and cement and concrete to design channels for the water to follow through without causing erosion. Below are pictures showing rehabilitated asbestos mine dumps and unsealed open shafts and holes.



Figure 2.4: Management of asbestos mine dumps through rehabilitation

2.7 South African air quality guidelines and standards

The National Framework for Air Quality Management in South Africa makes provision for the establishment of air quality objectives for the protection of human health and the environment as the South African National Standards (SANS-1929, 2005). Such air quality objectives include limit values, alert thresholds and target values. The target, action and alert threshold in Table 2.3 below are used in the evaluation of settleable dust.

According to the SANS 1929, 2005 guideline states that, the target level is set at 300 mg/m²/day annually with no permitted frequency of exceedance. The Action Residential level of 600 mg/m²/day, averaged over 30 days period may be exceeded three (3) times within a year, however, the exceedance should not be in two (2) sequential months. The Action industrial level is set at 1200 mg/m²/day averaged over 30 days period within a year. The permitted frequency of exceedance is similar to the Action residential level.

Areas recording monthly average settleable dust rates that exceed 2400 mg/m²/day under the Alert threshold have no permitted frequency of exceedances. However, the first incidence of settleable dust rate exceedances requires remediation and compulsory report to the relevant authorities (SANS 1929, 2005).

Table 2.3: Settleable dust standards, targets, action and alert thresholds for dust deposition (SANS 1929, 2005)

Level	Settleable dust rate, D (mg/m ² /day)	Average period	Permitted frequency of exceeding settleable dust rate
Target	300	Annual	Long-term average
Action residential	600	30 days	Three within any year, no two sequential months.
Action industrial	1200	30 days	Three within any year, no two sequential months.
Alert threshold	2400	30 days	None. First time exceeded, triggers remediation and reporting to authorities.

According to the American Standard Testing Method (ASTM D1739-70, 2004; 2010) for measuring settleable dust (settleable particulate matter), the regulation stipulates that the settleable dust for residential areas must be kept below 600 mg/m² /day measured over a 30 days average and between 600 and 1200 mg/m² /day for non-residential areas as shown in Table 2.4

Table 2.4: The National Dust Control regulations (NDCR 827, 2013)

Restriction area	Settleable dust rate (D) (mg/m ² /day)	Average period	Permitted frequency of exceeding dust fall rate
Residential area	D < 600	30 days	Two within a year, not sequential months
Non-residential area	600 < D < 1200	30 days	Two within a year, not sequential months.

2.8 Available monitoring method for asbestos minerals

2.8.1 Passive sampling methods

Different methods of sample collection have been used in the history of environmental studies and some of such methods are presented below:

Single dust bucket unit (American Standard Testing Method (ASTM D 1739-1982)) is a crude method used for the monitoring and measurement of dust and its also locally approved through the South African National Dust Control Regulations (SANDCR no. 827 of 2013). This method consist of a 2 m stand, supporting bottom, a dust bucket and pegs to mounted the bottom of the stand into the ground surface. A collector/ container must have the following specifications: an open topped cylinder with vertical sides and a flat bottom, minimum 15cm diameter with a depth of 2 - 3 times diameter (Figure 2.5). It may be made of glass, plastic or stainless steel but glass is not preferable because it is fragile. The collector should thoroughly rinse the cylinder and use distilled/deionized water in the container so that the level is half of the container's depth when the test is started (Figure 2.5).

In cold weather, a sufficient volume of antifreeze should be added to prevent freezing, while in warm weather, sufficient copper sulphate as an algaecide should be added to give 15 mg/litre concentration. The stand design is the most debated aspect of the method. According to ASTM D1739 - 1970, the holder should not interfere with the operation of the collector in any way, a bird ring must be provided (Figure 2.6) and the top of the container should be 2.4 m minimum above the ground. Normally samples must be collected for every 30 days \pm 2 days. After 30 days, the container which was exposed for 30 days on site is replaced with another one with half distilled/deionized water for another 30 days.



Figure 2.5: ASTM D1739:1970, ASTM D 1739:1982 and extended dust bucket

- Single dust bucket unit (American Standard Testing Method (ASTM D 1739:1982))** describes a single monitor which is deployed following the ASTM standard test method for collection of settleable dust rates (Environment Agency, 2003). This method employs a straightforward device comprising a container shaped like a cylinder (in the original method 50 % full-deionized water) exposed for 30 days. The cylindrical container (bucket) is supported by a metal frame so that the top edge container is 2 m above the ground. The dust is settled into the bucket vertically in possible ways: dry settleable or wet settleable. The elevation from the bucket rim to higher objects within 20 m should not exceed 30 m from the horizontal (ASTM International, 1982).

Two versions of the ASTM standard exist with only a bird ring around the top edge of the bucket. In South Africa ASTM D 1739:1982 has been in use for more than 25 years to monitor settleable dust on mines and industrial sites and it is still in use today. ASTM D 1739: 1982 requires the addition of water into the bucket in an effort to improve settleable dust retention. The ASTM D 1739:1982 is not legislated and regulated in South Africa and the legislated and regulated method in South Africa is ASTM D 1739:1970. The method is adopted and used as a reference method for the monitoring and measuring of settleable dust (Kwata, 2014).

Figure 2.6 shows different wind shield design for the ASTM D1739:1998 and are similar to the above mentioned units. Except this method has a windshield and extended dust bucket unit and the windshields designs are not of the same design. ASTM D1739:1998 method is not legislated and regulated in South Africa but researchers have applied the method to test the performance of the method, which gives high settleable dust rates results. This method also shows that it can be used for mining activities and is deployed in residential areas for research.



Figure 2.6: ASTM D1739:1998 with different windshield designs

- **Surface dust** or soil is usually collected on the earth surfaces using a plastic brush. A previous study by Moja *et al.* (2016) used the same method and the reason for using the method is that only settleable dust falls in the dust bucket unit also on the ground surface.

- **Sticky tape** is used to collect dust trapped on hard surfaces around the house including TV's, kitchen units, door frames and roof.

2.8.2 Active sampling or monitoring methods

- **AirCon 2-high volume sampler**) is used to collect airborne asbestos fibres on a specially graded filter material. The prescribed fibres sizes are physically counted using phase contrast microscopy or any other relevant instrument (MDHS 39/4 limit, 1995).
- **E-sampler** is a dual method airborne particulate matter monitoring instrument that use both the light scatter and gravimetric methods. The instrument can be used to monitor particulate matter pollution continuously and selectively per size in different periods per 24 hours, per week, per month or per seasons. The sample is also deposited on the filter where physic-chemical characteristic studies can be undertaken (EnviroCon manual and Moja and Mnisi, 2013).
- **Surface water samples** have also been collected for mineral content determination.

2.9.4 Analysis methods used from previous studies and used for this study

Various analytical techniques have been used to characterize geological materials and a few examples are presented below:

- **X-ray fluorescence (XRF)** is used to determine oxides of cations that exist in geological material. Many studies have used it to validate the presence of silicate material (Crowley, 2016). The instrument uses a primary x-ray that is ionizing to the core electrons of the atoms of the element in the sample, thus giving rise to a secondary radiation which is characteristic of the analyte element.
- **X-Ray diffraction (XRD)** is commonly used in mineralogy studies “and is” capable of identifying and quantifying the different minerals that are present in geological sample materials (Price, 2009).

X-Ray Diffraction determines the mineral composition and indicates dominant minerals and their contribution to generation of airborne dust contaminated with asbestos dust (Perkins and Harvey, 1993).

Restrictions:

- XRD is not as sensitive as SEM/EDS and generally requires about 4 mg of material for good counting statistics. In some case the filters did not have enough crystalline powder to generate a pattern.
- The XRD analysis employed here provides an estimation of the weight percentage of minerals present. Further method development is required to perform quantitative analysis.

Exceptions:

- Where very little particulate material was on the filter surface, as much material as possible was gathered, but usually pieces of filter material as well.
- Where the material on the filter surface formed a solid layer, pieces were chipped off and prepared.
- **Scanning Electron Microscope-Energy Dispersive Spectroscopy (SEM-EDS)** is an instrument that is used to determine the shapes, sizes, diameter, width, height, length and other morphological features of particles that make up geological sample materials (Sebaiwa, 2016; Atanastova, 2016). Scanning Electron Microscopy – Energy Dispersive Spectroscopy determines “morphology which includes the size, shape, length, width and types of asbestos groups detected on the filtered dust, surface dust and trapped dust samples. The trapped dust samples :are mounted on specialized filter holders for SEM-EDS investigations. Surface dust samples area were extracted from the filters and analyzed by XRD as powder specimens. For SEM analysis, powders are prepared as grain mounts. All specimens for SEM-EDS are coated with carbon to provide a conductive surface for optimum imaging and X-ray microanalysis. The analysis assists with the understanding of the general behaviour of settleable dust and characterization of airborne dust contaminated with asbestos dust (Brime, 1985).

- EDS check: at the start of each day's work a spectrum of cobalt metal was acquired to check that the peak positions were correct. The software uses the information about beam current, voltage etc. from this spectrum as one of the input values into the algorithm that calculates the elemental percentages.
- Upon inspection of each sample, one area, with as many large (more than 5 micron) particles of as diverse a nature as the sample allowed, were chosen.

Restrictions:

- Particles smaller than about one micron do not generate a spectrum with enough information to effect an identification. This has to do with interaction volume and was explained in a separate document.
- When particles lay close together, the interaction volumes can overlap and mixed spectra obtained.
- The **phase contrast microscope** is used for surface characterization of solid samples and include asbestos fibre count (MDH 39/4 limit, 1995).

Each visible image is observed and each regulated fibre size is counted to determine the total number of the fibres present.

Microscopic methods and other methods provide evidence to determine the identity of the type of asbestos and positive identification results in both crystallographic and element data required (Ross et al., 1984). Asbestos fibre density was determined by using SEM and the asbestos microscope to count particle dust/fibre and this also detected asbestos mineral groups and other silicates minerals using phase contrast microscopy. Asbestos load counts were done by phase contrast microscope.

- **Infrared Spectroscopy** is used to analyse samples containing asbestos fibres through absorption bands with asbestos fibres ranging from 3600-3700 cm^{-1} in the infrared spectrum associated with asbestos fibres (specific hydroxyl bands) and the 600-800 and 900-1200 cm^{-1} ranges (specific absorption bands for various silicate minerals) (Hodgson, 1985).

The non-asbestic-form amphiboles absorb within wavelength bands and infrared spectroscopy is not definitive for identifying asbestos.

2.10 Summary

The chapter gives a detailed overview of asbestos mining in the global, regional and local context. It covers the different environmental liabilities that are associated with asbestos mining, associated health effects, management of asbestos and other mining waste, related environmental legislations, monitoring and analytical techniques that are commonly used to characterize environmental pollutants. It also give a brief description of the passive and active samplers/methods used for this research and analytical techniques used to analysis the samples collected.

The next chapter addresses details of the research design which is divided into the pilot phase, the fieldwork phase and the laboratory phase. The chapter gives a detailed description of the study areas, sampling points, fieldwork and laboratory methods used for samples collection and analysis of collected samples, types of samples collected and dust monitoring units used.

CHAPTER 3: RESEARCH DESIGN AND METHODOLOGY

3.1 Introduction

The chapter encompasses a detailed description of the study area, reasons for selecting the study areas, geological formations, types of samples collected, methods sample treatment and analyses.

3.2 Location of study areas in South Africa

Figure 3.1 shows distribution of asbestos mines across the country. Asbestos mines in Limpopo Province are situated in Ga-Tshwene - Molemang Village (Site A), Ga-Mafeke – Mathabata (Site B) and Penge – Burgersfort (Site C, D and E). In Mpumalanga Province asbestos mines are situated in Nelspruit (Site A, B and C), Malelane (Site D) and Badplaas (Site E).

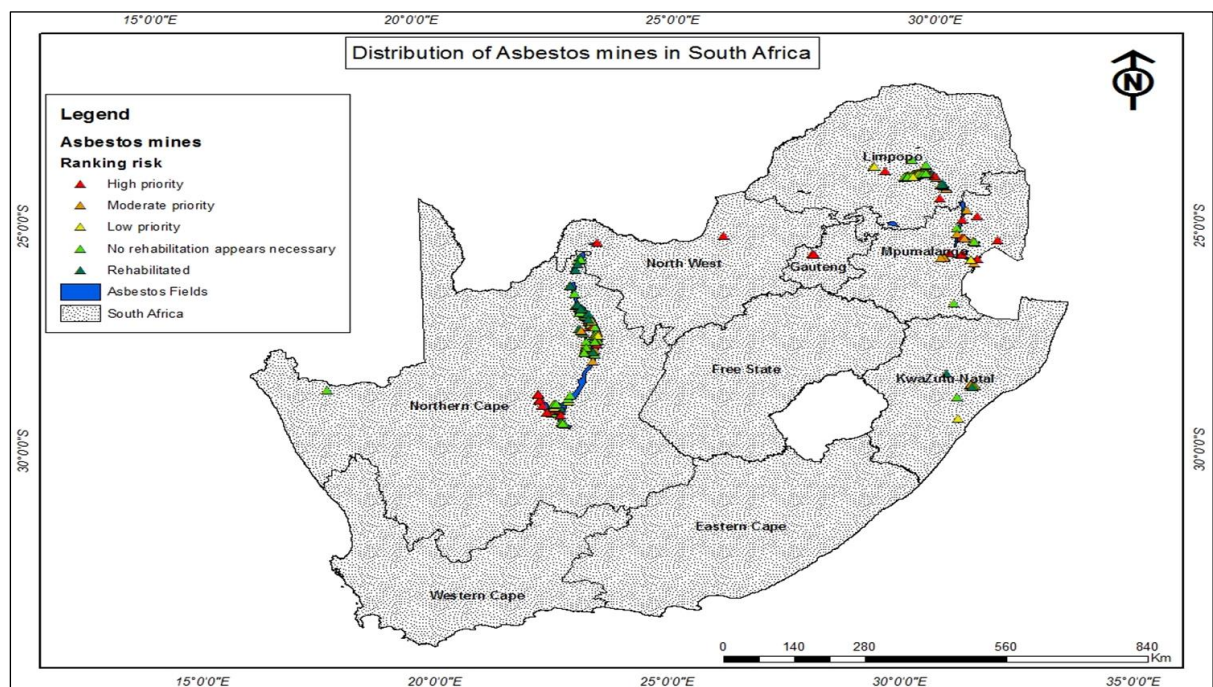


Figure 3.1: Map showing the locations of asbestos mine per province in South Africa (Madikizela, 2016)

3.3 The identity of study areas, geology and sampling points

The chosen study areas are in Limpopo Province, which is characterized by both rehabilitated and unrehabilitated asbestos mine dumps, and in Mpumalanga Province, which has only unrehabilitated asbestos dumps. The interest in these asbestos mine dumps is due to their close proximity to human settlements and possible health impacts to those who are exposed to the fibres.

3.3.1 Limpopo Province

The study was undertaken within local communities (Ga-Manglemang Village, Ga-Mafefe - Mathabata Village, Penge Village and Taung Village) located near the old and abandoned asbestos mine dumps in Limpopo Province (formerly Northern Province) in South Africa. Figure 3.2 shows five asbestos dumps: dump B has been fully rehabilitated: dumps A, C, D and E are partially rehabilitated.

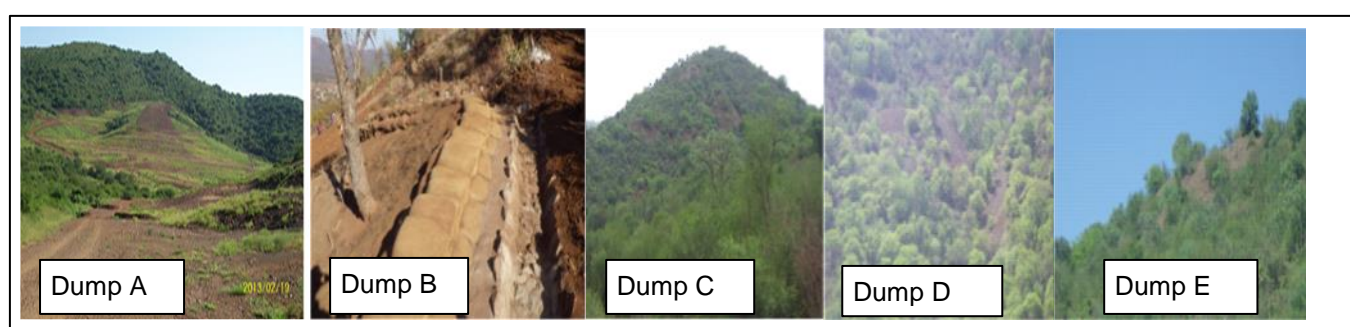


Figure 3.2: Location of asbestos mine dumps in Limpopo province

The province has bushveld, majestic mountains, primeval indigenous forest, unspoilt wilderness and patchworks of farmland (MYEP, 2015). The geology of the province contains the Transvaal and Chuniespoort group; carbonate rock formation (contains iron and magnesium embedded in the rocks) form part of the dolomite series in succession near the top, which is followed by carbonate rock formation. Most rocks in the province belong to the Malmani SubGroup and Penge formation (Hart, 1988).

The most common rocks found in the province are shale, dolomite, chert, quartzite, conglomerate, breccia and diamictite (Visser, 1989). Penge is an old town situated approximately 48 km north-west of Burgersfort, in the Greater Tlhabatlwa Local and Greater Sekhukhune District Municipalities.

The asbestos mines were located south of the Pietersburg asbestos fields (Sluis-Cremer, 1965) and extend in an 80 km arc from Malisdrift in the north-west to the confluence of the Olifants and Steelpoort Rivers in the southeast (Hall, 1930). The Penge asbestos mine and village are located in the south-eastern extremities of the Pietersburg asbestos field (Davis et al., 2004). Ga-Malemang village is situated in north-east of the province where the capital city of province is located on the road to Polokwane. The village is 30 km away from Polokwane and along the road there is a smelter. Ga-Mafefe village is situated in the north-east of the province next to Bewaarskloof where there are old and abandoned asbestos mine dumps. Figure 3.3 shows detailed lithostratigraphy within the study area and the location of asbestos dumps in the Limpopo province.

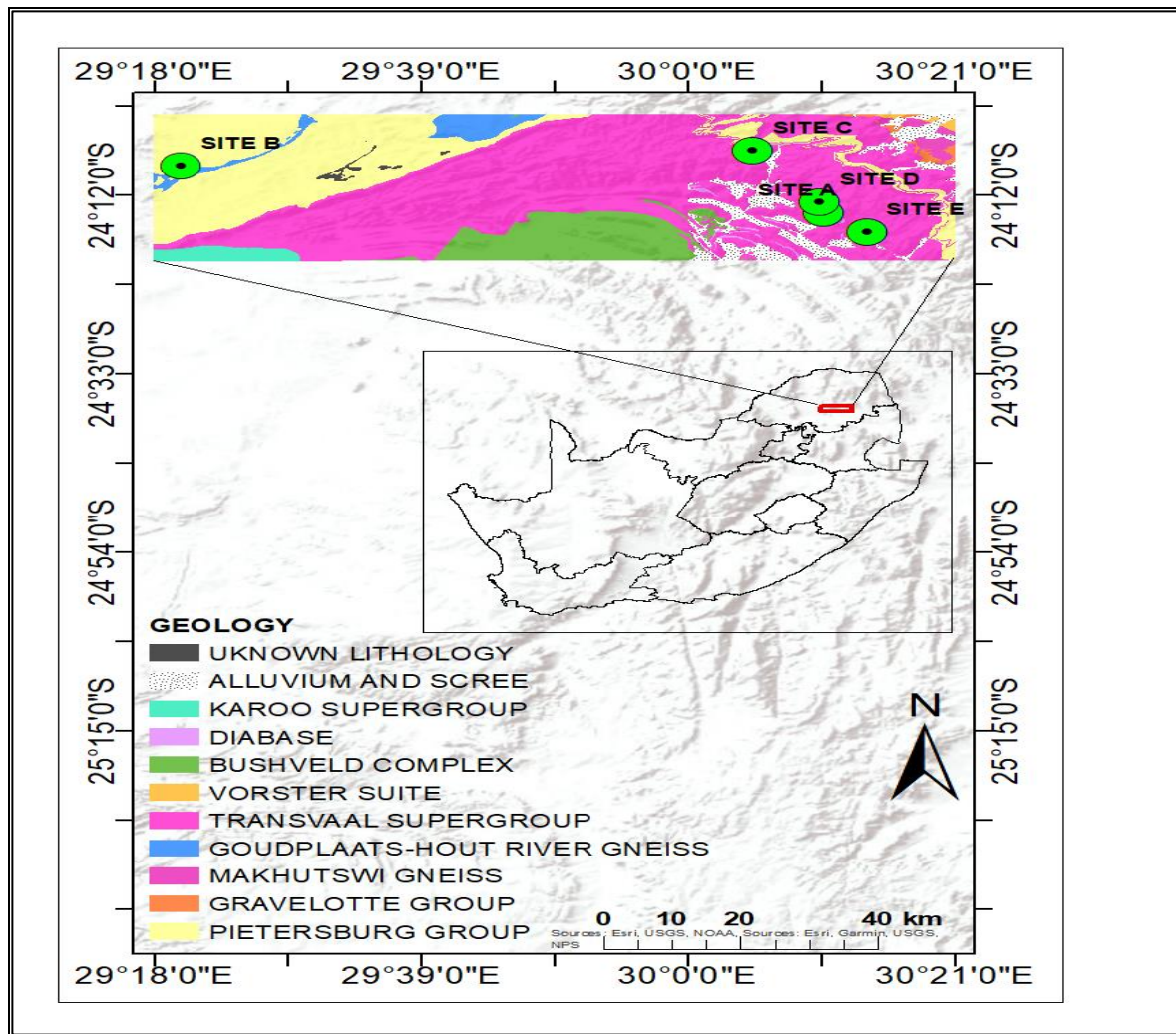


Figure 3.3: A Geological map of Limpopo Province and showing location of asbestos mines dumps (Mandende, 2017)

The characteristics of these dumps are further explained in Table 3.1. Five (5) sites are located within 3.5 km of the nearest human settlements. The estimated height of mine dumps which were accessed were all below 40 m. Dump B is fully rehabilitated and Dumps A, C, D and E are partially rehabilitated. The mine dumps are visible to the nearby human settlements. Dump B is fully rehabilitated but there are still complaints from the human settlements concerning continued exposure of asbestos dust especially during the dry and windy season.

Table 3.1: Distance from mine dumps to nearest human settlements and description of the mine dumps in Limpopo Province

Name of Mine Dumps	Distance from Mine Dump to the nearest human settlements (km)	Estimated Height of Mine Dump (m)	Latitude	Longitude	Description of Mine Dump Site
Dump A	0.68	20	24.23578	30.17595	Dump visible. Half rehabilitated.
Dump B	2.12	35	24.14348	29.33403	Dump rehabilitated, covered with sacks and top soil.
Dump C	2.56	36	24.11299	30.08272	Dump visible. Rehabilitated and covered with natural grass and trees.
Dump D	1.05	35	24.21489	30.1702	Dump is partially rehabilitated, and dump it is still visible.
Dump E	1.70	35	24.27261	30.23306	Dump is visible, is partially rehabilitated.

3.3.1.1 Sampling sites

In Limpopo Province five sampling points were identified and the dust monitoring units were installed in the human settlements; the province is known for mining amosite from the amphibole mineral group:

Site A: the site is located near the town of Penge about 48 km to the north-west of the town of Burgersfort in the Limpopo Province. The area coverage is 28.54 km² (11.02 sq mi) and population is 2,819 (Census, 2011; IDP, 2016). The site is partially rehabilitated and the process of rehabilitation involved very few earthworks and minor repairs to fencing and was primarily intended to establish vegetation over the extremely steep slopes of the Penge area in an effort to curb future erosion and the possible re-exposure of asbestos covered here.

The hospital is situated 40 km from Burgersfort Town. According to several published articles, the Penge area is known to be the area of asbestos mining, which created major environmental and health problems and where families lost their loved ones due to exposure to asbestos without any education about the danger of asbestos fibres and how asbestos is deadly to human well-being (Cornelissen, 2013).

Site B: Ga - Manglemang Village, situated 40 kilometres East-South-East of Polokwane in Limpopo Province, is an abandoned asbestos mine located on the farm Baviaankop 373 in the Chuniespoort region of Limpopo Province. The village is under the leadership of Chief Klaas Mapheto. The village is under Lepelle-Nkumpi local municipality and the population is 890 (Census, 2011). The site is fully rehabilitated with regard to mine dumps. Although some asbestos mines in the Mafefe area were either partially or completely rehabilitated in the past, many asbestos mines, shafts and adits were left unrehabilitated due to technical difficulties or for financial reasons. The Manglemang Village site currently resides in the jurisdiction of the Baviaankop traditional authority. It is a previously unrehabilitated asbestos mine adjacent to the Baviaankop Village/farm.

There are no active buildings on the site, but the site is used as a thoroughfare for pedestrians and animals from the local communities to access the river. This directly exposes people and animals to asbestos fibres and the risk of developing asbestos related diseases on a daily basis.

The secondary footprint of the dump and exposed asbestos workings have been increased due to wind and water erosion. Manglemang Village, known as Baviaankop farm, where asbestos was mined also left major environmental and health problems and high mortality. The site was rehabilitated in 2015 when asbestos mine dumps were covered with topsoil aligned with sacks filled with seed and manure and a tunnel was also constructed so that the water could flow through during the rainy season (Meyerowitz, 2015).

Site C: Ga-Mafefe clinic is situated in the East-North of Ga-Mathabata under leadership of the Chief Setlamorago. The area coverage for the village is 1,219.090 and population is 2000 (Census, 2011). It is one of the areas heavily impacted by past asbestos mining activities. Mafefe forms part of Capricorn District Municipality, about 200 km south-east of Polokwane.

Asbestos mining started between 1917 and early 1800's (Petja, 2001). The clinic is 100 km from Polokwane, capital city of Limpopo Province. The area is 10-20 km away from Bewaarskloof Game Reserve where asbestos was also mined and which contributed to environmental and health problems in Ga-Mathabata and Penge areas. Natural vegetation grows on top of the mine dump and only few shafts are sealed.

Site D: Land owner's yard at Marekaneng Village is situated in the North –West of 48 km away from Burgersfort town. The area is known as the location of former asbestos mining and also left major environmental and health problems. The site is partially rehabilitated and some asbestos mine dumps are not rehabilitated. The village estimated area coverage is 800 and population size around the Marekaneng village is 1300.

Site E: the site is located in Taung Village and in the North-West about 60 km to the town of Burgersfort. The site is located on state-owned land on the farm Kromellenboog 132 KT in the Greater Tubatse District Municipality, Ward 22 in Limpopo province. The village estimated area coverage is 800 and population size around the Taung village is 900. The area is known as the location of former asbestos mining and has also left major environmental and health problems. Also, the area is known for failure of rehabilitation and still unsealed shafts pose physical damage.

3.3.2 Mpumalanga Province

This second study area is situated in Mpumalanga Province and the asbestos mine dumps are near the local communities around Mbombela (formerly Nelspruit), Malelane and Badplaas. Mbombela is the capital city of the Mpumalanga Province and is in the eastern part of the province. All the five dumps in Mpumalanga Province are not rehabilitated, but are partially covered with natural vegetation.



Figure 3.4: Shows five asbestos dumps: A, B, C and E are unrehabilitated

The province is known to have pine trees, escarpment and mountainous areas. Mpumalanga Province contains Tjakastad, Komatipoort Group and Transvaal SuperGroup. The common rocks found in the province are sandstones, shale, muchison, greenstone belt and intrusive granite. Komatities often display spectacular textures of skeletal crystals (known as spinifex textures) which branch out like fern leaves. The textures and the chemical makeup of the rocks can be deduced from Komatities lavas crystallized exceptionally rapidly from very hot and probably water-rich molten magma (Ehlers and Vorster, 1998). Although gold was the main attraction in the Barberton greenstone belt for many years, the early prospectors who combed the hills also drew attention to the presence of other mineralization types in the region. These included occurrences of chrysotile asbestos, iron, barite, magnetite, talc, tin, antimony, mercury, nickel-copper, zinc and verdite-buddstone. In later years some of these commodities yielded important deposits and were significant producers particularly of chrysotile asbestos, magnetite, talc, barite and iron ore. Minor occurrences of stibnite, cinnabar, cassiterite and verdite were mined in places and the presence of nickel-copper and zinc-silver-lead was noted, but never exploited.

Chrysotile asbestos was first noted in the Kaapsehoop area in 1905, but was only exploited from 1915 onwards. It occurs in ultramafic rock formation and its hydrated magnesium silicates differ from other types of asbestos, fall within the serpentine mineral group and contain only one cation magnesium (Phillips *et al.*, 2012). Figure 3.5 shows detailed lithostratigraphy within the study area and the location of asbestos dumps in the Mpumalanga province.

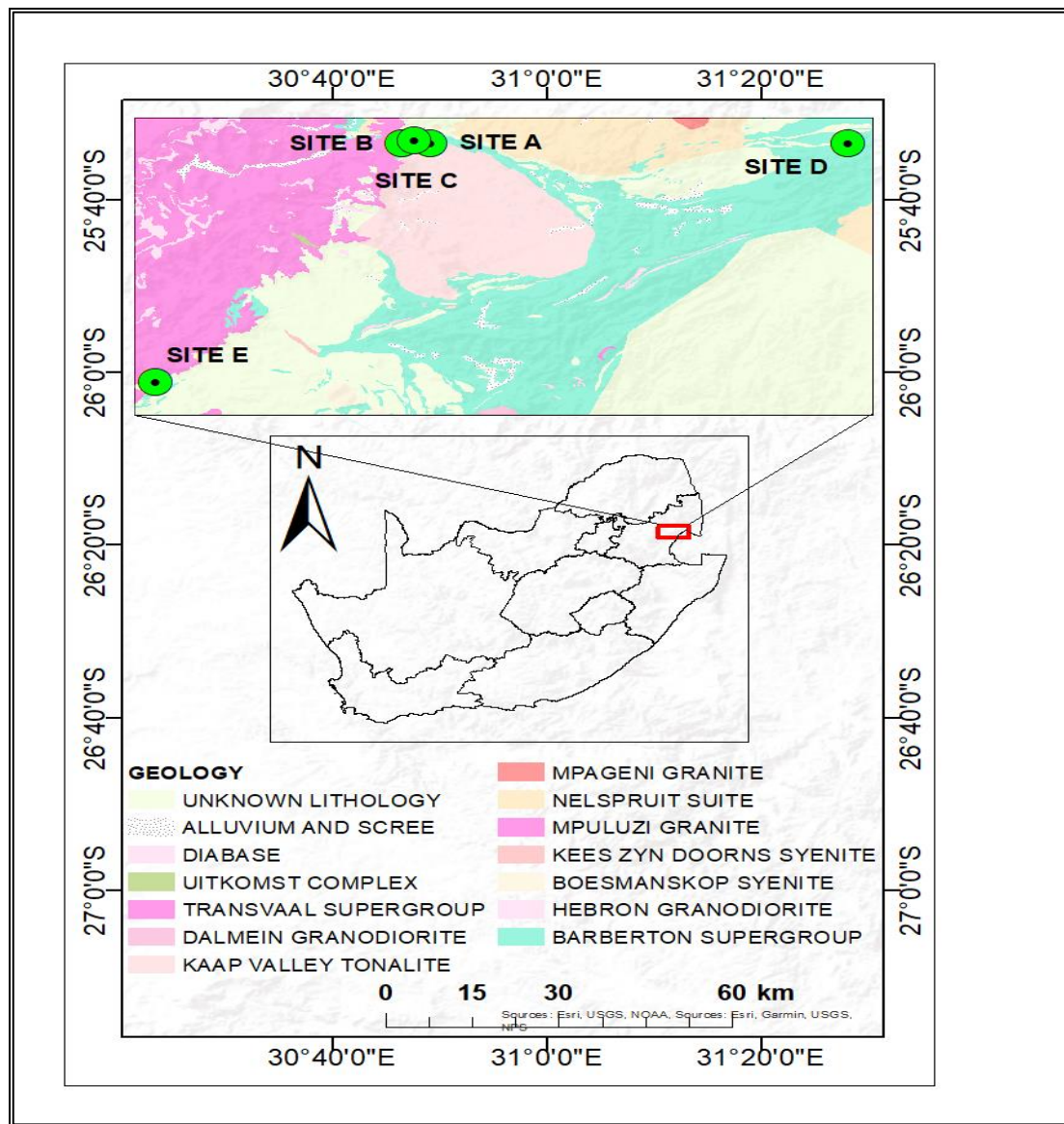


Figure 3.5: A geological map of Mpumalanga Province and locations of asbestos mines dumps (Mandende, 2017)

Figure 3.5 shows detailed lithostratigraphy within the study area and the location of asbestos dumps in the Mpumalanga province. The characteristics of these dumps are further explained in Table 3.2. Five sites are located within 2 km of the nearest human settlements. The estimated height of mine dumps which were accessed were all below 50 m. Dumps A,B,C, D and E are unrehabilitated. The mine dumps are visible to the nearby human settlements. The visible paths on the mine dumps indicate erosion during rainy season and wind-blown asbestos dust from the asbestos mine dumps to the human settlements.

Table 3.2: Distance from mine dumps to nearest human settlements and description of mine dump sites for Mpumalanga Province

Name of Mine Dumps	Distance from Mine Dump to the nearest human settlements (km)	Estimated Height of Mine Dump (m)	Latitude	Longitude	Description of Mine Dump Site
Dump A	0.11	35	25.55689	30.771667	Un-rehabilitated dump, is visible and at the centre in a farm.
Dump B	0.60	30	25.55558	30.81119	Un-rehabilitated dump, is visible and small portion is covered with natural vegetation.
Dump C	0.32	40	25.55229	30.79229	Un-rehabilitated dump, is visible and small portion is covered with natural vegetation.
Dump D	0.75	45	25.55778	31.465833	Un-rehabilitated dump, is visible and small portion is covered with natural vegetation.
Dump E	1.74	40	26.01982	30.3658	Un-rehabilitated dump, is visible and is on a mountain / hill

3.3.2.1 Sampling sites

In Mpumalanga Province five sampling points were identified and the dust monitoring units were installed in the human settlements. The province is known for mining chrysotile asbestos from the serpentine mine group (Hart, 1988). A description of the sites follows.

Site A is located in Kaapsehoop guesthouse farm and in the North-West about 20 km away from Mbombela, the capital city of Mpumalanga Province. The area coverage is 0.35 km² (0.14 sq mi) and the population is 182 (IDP, 2016).

The area is surrounded by pine trees and water flowing from open shafts is used for domestic purposes. There are still unrehabilitated asbestos mine dumps surrounded by houses and inhabited by people and horses. The area is surrounded by rock field formation near Nelspruit which are made of quartzites of the Black Reef formation of the Transvaal supergroup.

Site B is located in Stella South farm house in the North-West, owned by SAPPI and situated 20 km away from Mbombela, capital city of Mpumalanga Province. The area is surrounded by pine trees owned by SAPPI and community, farm hostel and farm houses and the site is unrehabilitated. The estimated area coverage is 300 and population size around the Stella South farm house is 30.

Site C is located in Jourbertsdal hostel farm in the North-West. The farmworker's hostel owned by SAPPI is situated 20 km away from Mbombela, capital city of Mpumalanga Province. The area is surrounded by pine trees and farm hostels, owned by SAPPI and the site is unrehabilitated. The estimated area coverage is 1000 and population size around the Jourberstdal hostel farm is 50.

Site D is located in Senekal farm and next to a farmworkers' hostel. It is situated in the Eastern-North part of Mpumalanga Province and the site it is 10 km away from Malelane. The estimated area coverage is 700 and population size around the Senekal farm is 40. The area is along the road to the Mozambique and Swaziland border gates. The site is unrehabilitated and is visible, partially covered with natural growing vegetation.

Site E is located on Rietfontein farm and in the North-West, 40 km away from Carolina and the farm has a fishing pond. The estimated area coverage 3000 and population size around the Rietfontein farm is 25. The area is surrounded by other farms and is along the road to Barberton. The site is unrehabilitated; mine dumps are visible on top of the mountain; the old infrastructures are still visible and there is also a sign stating that asbestos is dangerous.

3.4 Methodology

A desktop, a pilot, field and laboratory studies were undertaken during this research. A desktop study of the study area helped in understanding the location, knowing the terrain or topography better and identifying possible sampling sites using the Google earth technology (Google Earth). A pilot study was undertaken to compare the performance of two settleable dust methods in the search for cost effective method of collection and analyses of asbestos mineral hazards. The fieldwork study was undertaken to verify the identified sampling areas and to collect samples. The laboratory studies involved optimizing the different measuring parameters, which led to the modification and application of optimized method to determine the presence of asbestos load in a form of mineral count.

3.4.1 Sample collection methods

Detailed and specific sampling methods are described below.

3.4.1.1 Passive and active methods of sample collection

A pilot study for the purpose of comparing the performance of two commonly used settleable dust methods. The first method, known as ASTM D1739:1998 has the windshield and is applied with water or without water. Both the second and third methods are known as ASTM D1739:1982 and ASTM D1739:1970 respectively are designed with a bird ring, do not have the windshield are applied with water only. ASTM D 1739:1982 method use a single bucket unit of extended or longer depth. In addition, the presence of an algaecide, 5 % CuSO_4 and NaOCl solutions in the water suspension medium made the sample easier to filter and led to higher dust retention yields. In the absent of algaecide solution make it difficult and it blocked/clogged filter pores such limit the efficient of the dust retention and filtration.

Figure 3.6 shows the ASTM D1739:1982, ASTM D1739:1998 and ASTM D1739:1970 all these methods are designed to measure and monitor dust. ASTM D1739:1982 and ASTM D1739:1970 are similar but only the ASTM D1739:1970 is recommended through the local National Dust Control Regulation no.827 of 2013. individual settleable dust collection unit is made of a single 5.0 L cylindrical bucket half filled with deionized water, which is placed on a 2 m high stand with a bird ring on top (Figure 3.6). The units are exposed on identified sites for a period of 30 ± 33 days before being replaced with clean ones. The exposed units containing settleable dust samples are transferred to the laboratory and filtered with a Buchner filtration system. After filtration, dried samples on filter papers are placed in the incubator to allow mass to stabilize before being weighed to determine the exact amount of dust that settled using gravimetric calculations ($\text{mg}/\text{m}^2/\text{day}$). Both methods were piloted in Mpumalanga province, which is known for asbestos mining activities and the North West Province as the control and is a known platinum group of metals mining region.

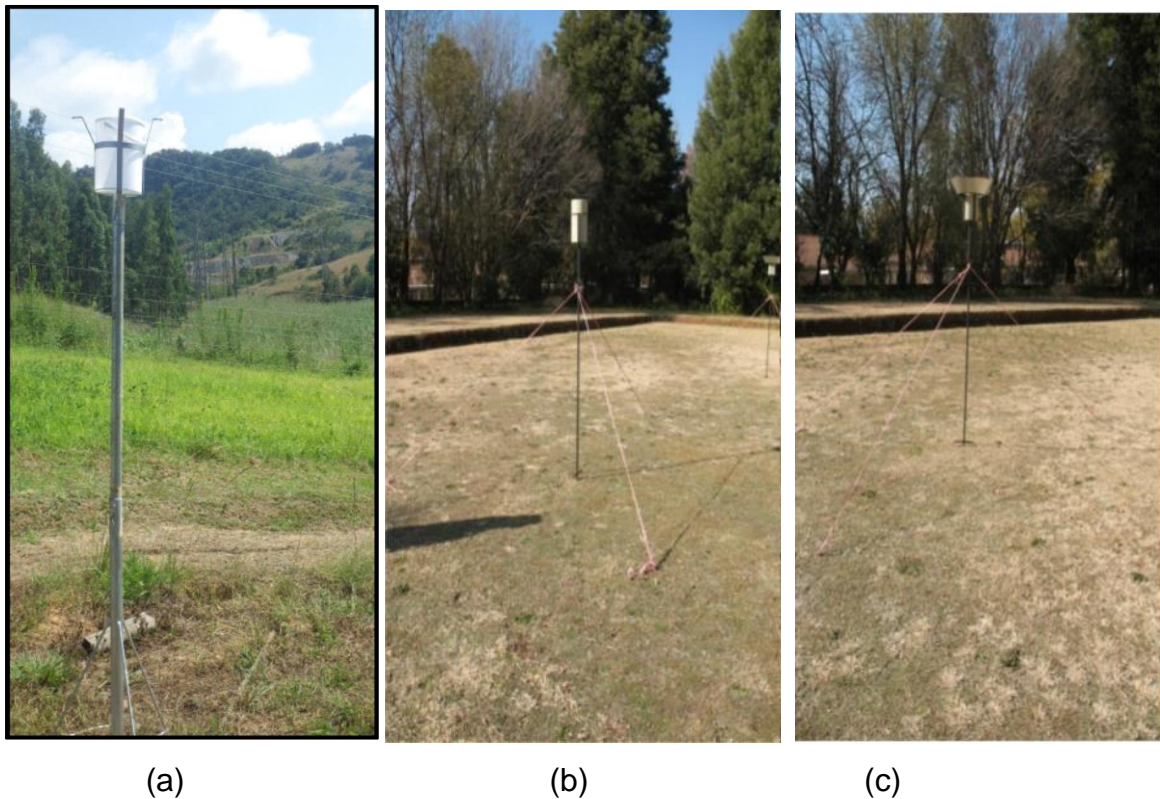


Figure 3.6: (a) ASTM D1739:1970 ;(b) ASTM D1739:1982 and;(c) ASTM D1739:1998

For this study, settleable dust samples were collected from April 2016 to June 2017 ,AirCon 2 high volume samplers and E-sampler airborne samples were collected from January to December 2017, surface dust and trapped dust samples were collected from November 2016 to July 2017 at chosen sampling sites that are within the human settlements situated near old and abandoned asbestos mine dumps.

Individual units were installed within the yards of five farmhouses, household yards, clinics and hospitals. The settleable method (ASTM D1739:1970) method was used and applied; it is a crude method designed to monitor and measure settleable dust rates and is approved by the government through the National Dust Control Regulation no. 827 of 2013. Active sampling methods used to collect and characterize airborne dust are the AirCon 2 sampler and the E-sampler. Figure 3.7 shows the active samplers (a) AirCon sampler, (b)cassette for fibre density collection, (c) fibre density collection, (d) E-sampler, (e) light scatter.

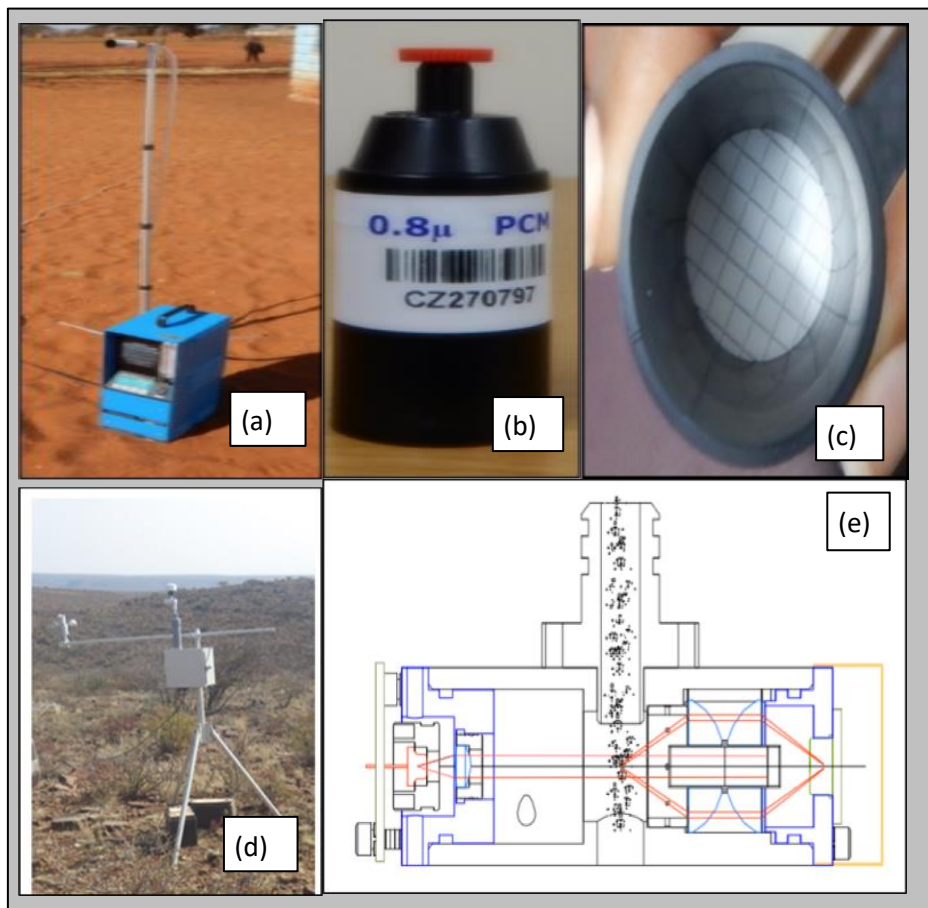


Figure 3.7: Active samplers (a) AirCon sampler, (b)cassette for fibre density collection,(c)fibre density collection,(d)E-sampler ,(e) light scatter

Aircon-2 high volume air sampler uses a specially graded 25 mm diameter mixed cellulose ester (MCE) membrane filters or pore size 0.8 μm with black grids that allows 2880 L of air to be pumped in. In the beginning, the samples were collected at 4 hours intervals due to the limitation of the life of the internal battery. However, the data that has been reported from January to December 2017 has been run in a sequence of 24 hours as prescribed by the manufacturer using AC electricity power supply (AirCon 2 High Volume manual, 2016). For safety and protection against rain, the instrument was placed indoors, but the open-face filter cassette on a long hose was exposed on the outside through the window. The suction pump on the Air Con was set at a flow rate of 2 L/min, which was verified everyday (or every 24 hours) using a TSI mass flow meter 4100 series. The sampling time was set to 24 hours (1440 min) and the filter cassette was changed every 24 hours. However, due to having one AirCon 2 sampler, the sampler was used once a month at 10 different sites equally distributed in LP and MP. In twelve months, a total of 120 filters were used / exposed. That is, 5 sites x 12 x 2 provinces = 120 of exposed filters. Therefore, the total volume of air sampled is equal flow rate x sampling duration (2×1440) = 2880 L.

The E-sampler from Met One Instruments Inc. Oregon United States of America is a dual technology instrument that combines the real time measurement of the light scatter method and the gravimetric filter method where particles are pre-concentrated. An internal rotary vane pump draws air at the rate of 2 liters per minute (LPM) into the visible laser light sensing chamber used for measuring the number of particles in a particular volume of air. The instrument is capable of making 40 measurements per second and averaging them to get a representative particulate data per hour, day or month (E-sampler-9800 Manual, 2015). The E-Sampler was placed in the backyard of a clinic (26°42_01__S, 27°51_15__E) and sampling took place from January to December 2017.

Outdoor surface dust samples were collected around the dust fall monitoring units with the intention of collecting the same sample type of settling dust within the same square meter (Moja *et al.*, 2016). While the indoor surface trapped dust, samples were collected with a sticky tape on the hard surfaces in the house, see Figure 3.8.



Figure 3.8: (a) sticky tape substrate; (b)-(c) areas where trapped dust samples were collected with rolled sticky on hard indoor and on the window door; (d) samples in a storage container

The sticky tape is applied/placed on the unit and rolled to collect the trapped dust samples and thereafter the sample is stored in a storage container. When collecting the trapped dust samples, gloves and dust masks are worn to prevent contamination and for safety reasons. Trapped dust samples were collected on top of old kitchen units, wind screens of parked cars and on house windows, outside and inside, using sticky tape and stored in a storage container (Figure 3.8).

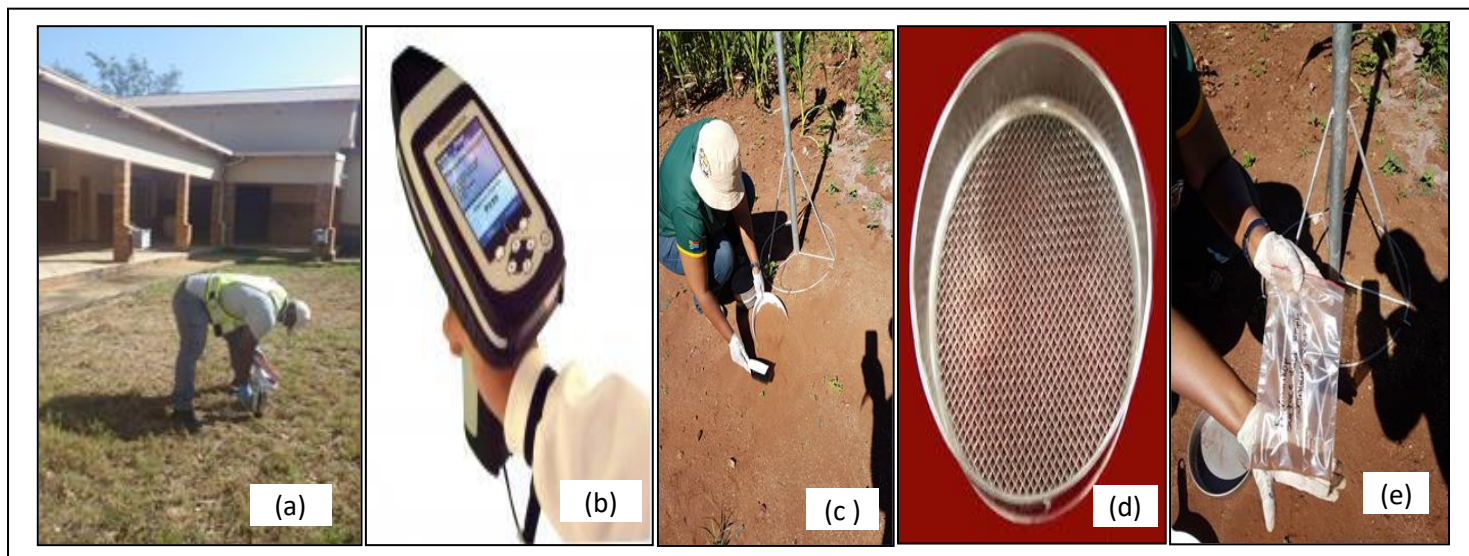


Figure 3.9: Passive samplers (a) asbestos detector screening; (b) handle asbestos detector / analyser; (c) surface sampling collection-brush, dust pan; (d) 1.8 mm pore size stainless steel sieve and ; (e) zipper plastic

Both the visual method and a hand held asbestos analyser were used for screening purposes before the collection of surface dust samples. Supplementary surface dust samples were collected from fifteen different sampling points by sweeping ground surface material/dust with a clean brush into a dust pan. Then surface material/dust collected in a dust pan was stored in medium zipper plastic bags and labelled. Before the surface dust analysis, the samples were prepared by sieving them with a 1.8 mm stainless steel sieve to remove large materials/grains (Figure 3.9).

3.4.1.2 Laboratory treatment and analysis methods

This subsection explains in detail methodologies that were followed to treat and analyze the different dust samples collected in the air, on ground surface and in surface water.

Settleable dust on filter substrate

A standard method for collection and analysis of settleable dust adopted from the South African National Dust Control Regulations (SANDC R 827, 2013) was used in the research. This method specifies dust particles being measured with aerodynamic diameters of less than 100 μm .

Settleable dust monitoring units are placed within the nearest human settlements. The bucket is hoisted on a 2 m stand above the ground.

Calculation of the settleable dust rate

The settleable dust rate is defined as the rate of the deposition of the dust (DustWatch, 2015). Settleable dust sampling measures the fraction of dust greater than 30 μm diameter that will settle from the atmosphere under force of gravity. Single bucket settleable dust monitors/units were deployed following the American Standard Testing Method (ASTM D1739-1970) for collection and analysis of settleable dust.

The cross-sectional area of the bucket unit is a standard constant in all of the calculations representing the area over which settleable dust collection has been made:

$$A = \pi r^2$$

Diameter of the bucket unit is: $d = 0.18 \text{ m}$

Therefore, the radius, $r = 0.09 \text{ m}$

$$A = \pi(0.09 \text{ m})^2$$

$$A = 0.02545 \text{ m}^2$$

The weighted (W) mass is derived by subtraction of the mass of the blank filter paper from the mass of the filtered paper.

Weighted mass of the dust sample = filtered paper (g) – blank filter paper (g).

Time (T) is described as the duration of the sampling period in days (± 30 days).

All units should be expressed in milligrams and the value of the milligrams /square metre/day ($\text{mg}/\text{m}^2/\text{day}$) derived from the formula:

$$\text{Settleable dust rate} = \frac{W}{A \times D} \quad (1)$$

Water matrix and sample on filter substrate

Water substrate from the filtration process the sample on the filter substrate is placed in incubator for the filter to dry for 24 hours. The water substrate is disposed in the basin. The laboratory basin must be cleaned with a soap and deionized water. Then, the sample on filter substrate is weighed and calculated for the mass concentration and treated with carbon for the XRD and SEM-EDS analysis.

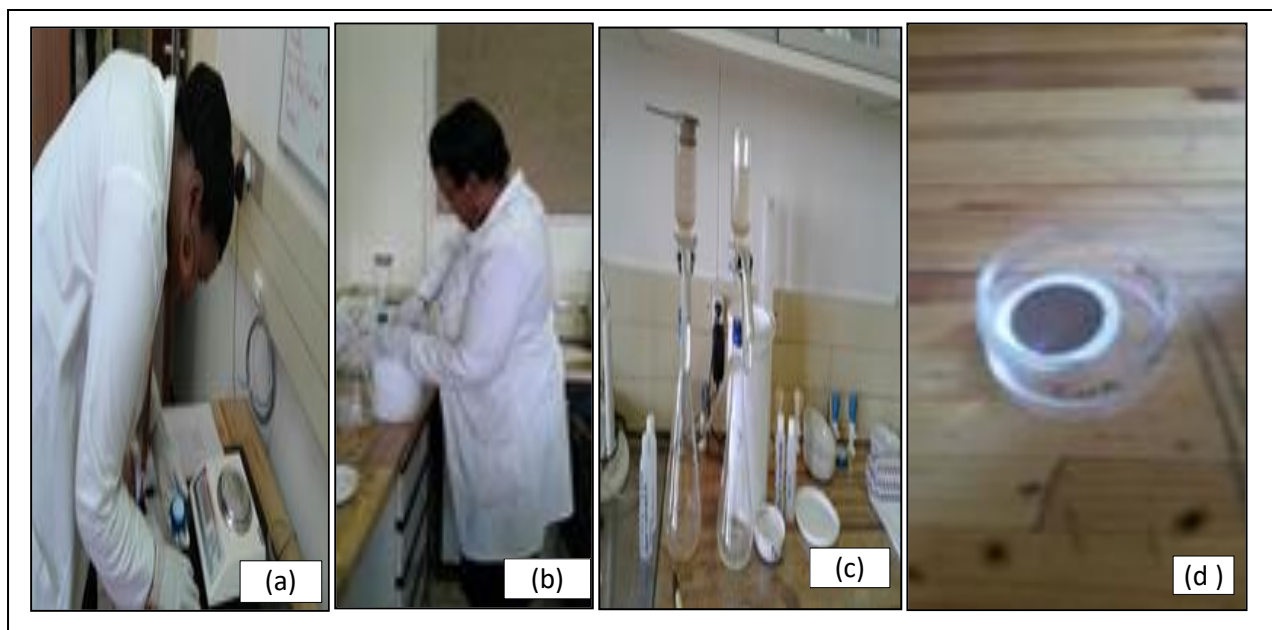


Figure 3.10:(a)preparing weighing of the blank filter;(b) using spatula and distilled to transfer collected dust from the walls of the dust bucket;(c) filtering collected dust on filter;(d) filtered dust sample in a storage container

AirCon 2 sampler on filter substrate

This equipment is a standard method designed to specifically collect airborne asbestos fibres in real-time for concentration measurement purpose. The method was used as a validation technique for the presence of asbestos silicates in environmental samples. The unit is used operated by AC electricity power supply and battery. (Figure 3.7). The filter (or part of the filter) was mounted on a microscope slide and rendered transparent ('cleared'). The part of the filter paper is then vaporized using acetone in a vaporizing machine.

Vaporization makes filter paper clear for analysis under the microscope. Fibres of appropriate dimensions on a measured area of filter were counted visually using phase contrast microscopy (PCM) and the number concentration of fibres in the air calculated / counted. Countable fibres are defined as particles with length > 5 µm, width 3:1. Fibres having widths < 0.2 µm may not be visible using this method and the PCM count represents only a proportion of the total number of fibres present. The method does not identify the fibre type present but fibres with widths greater than about 1 µm may show optical properties that are inconsistent with asbestos and it is permissible to eliminate these fibres from the count to determine compliance with the asbestos control limit or other limits. Discrimination against non-asbestos fibres was done after the initial total count has been completed due to the destructiveness of the XRD and SEM/EDS methods.

The airborne asbestos concentrations were calculated using the formula:

$$C = 1000 N D^2 / V n d^2 \text{ fibres per millilitre (f/mL)} \quad (2)$$

where N is the number of fibres counted;

n is the number of graticule areas examined; *200 fields*

D (mm) is the diameter of the exposed filter area; *25 mm*

d (µm) is the diameter of the Walton-Beckett graticule; *100 µm*

V (litres) is the volume of air sampled through the filter. *2880 L*
through filter cassette 4800 LM or 4.8 m³

E-sampler sample on filter substrate

The E-sampler uses a dual monitoring system, which comprises light scattering and gravimetric methods. It collects PM_{2.5} or PM₁₀ dust samples from ambient contaminated air by pulling a specified volume of air. In this research, this instrument was used for the first time to monitor airborne asbestos fibres. The instrument was also used as second instrument after the Air Con 2 sampler to validate the presence of asbestos in E-sampler exposed filters.

Then the number of dust particles in the air sample are counted as they pass through the light path through a build-in detector. The dust particles are then deposited on a 47 mm cellulose filter paper before exiting the unit.

Operating parameters for E- sampler:

- Operate in two ways gravimetric and light scatter
- PM₁₀, PM_{2.5}, PM₁, TSP monitoring, but use one inlet size per time.
- Operate for 30 hours without heater and 10 hours with heater
- It is recalibrated after every 2 years operation
- 2 LPM internal rotary vane pump draws into the sensing chamber where it passes through visible laser light

The exposed E-sampler filters are stored in sealed petri dishes until they are treated or prepared to measure the total number of fibres in the samples.

Trapped dust sample on the sticky tape substrate

The trapped dust samples were collected on a sticky transparent tape. A piece of sticky tape was used to collect the dust that settled on hard surfaces such as window panes (indoor, outdoor, unit and roof): furniture in and outside the houses within the study areas and wind screens of old cars (Figure 3.9). The samples were individually secured in sealed petri dishes and placed in labelled zipper plastic bags. Three replicate sticky tape dust samples were collected from each site.

Ground surface dust samples

Surface dust samples were can commenced. The samples were sieved on 500 µm pore size stainless steel sieves to remove large dust particles and were then milled, crushed and splitted to produce fine dust material before the analysis. A quantified fine dust material was inserted on the special filter tray holder to generate the geochemical footprints the X-ray fluorescence instrument.

3.4.1.3 Sample preparation

Settleable dust samples procedures

The blank filter papers were placed on each of the watch glass fitted with the glass squat form beaker (Figure 3.10). The filter papers were manufactured by Munktell filter AB (Grade 389), with 47 mm diameter, 84 g/m² weight, 20 s/10 mL and 8 -12 µm retention rate. They are made of pure cellulose with an alpha cellulose content of almost 100 % and an ash content of less than 0.01 % (Filtration and Separation Technology, 2015).

The mass (in grams) of the blank filter paper before the filtering process was weighed on the mass balance (Figure 3.10) and recorded into the laboratory test book and placed back into the watch glass. The procedure for the blank filter paper weighing was repeated for other study areas. A pair of scissors was used to open the exposed bucket lids and the suspended material on the walls of the bucket unit was removed by using a spatula.

The samples were filtered using a millipore flask vacuum pump filtration system to determine the mass concentration of settleable dust material after weighing the mass of filter paper before and after filtration (Figure 3.11). The filtering process takes about two to three days. The process of filtering was repeated for the other study areas. On completion of the filtering process, the settleable dust filtered papers were stored in the watch glass fitted with the 250 ml glass squat form beaker and allowed to dry by evaporation of retained moisture at room temperature. The drying process takes about 24 hours and the settleable dust filtered papers were weighed on the mass balance (Figure 3.11) and the mass after filtering was recorded on the laboratory test report. The weighted settleable dust filtered papers were placed into the dust sampling containers.

Settleable dust samples were studied further using an X-Ray Diffraction (XRD) analytical technique to evaluate the mineralogical composition. The instrument was conditioned according to the CGS Mineralogy Laboratory Methods (Atanasova, 2016).

Exposed filters from AirCon 2-high volume sampler and E-sampler are used to collect airborne asbestos fibres on a specially graded filter material. The prescribed fibres sizes are physically counted using phase contrast microscopy or any other relevant instrument. The filter mounted from AirCon is cut into a quarter the place on a slide tray then slide tray is divided into 200 fields so that the filter asbestos fibre or material can be visible for the counting analysis. Then, fibres qualifying to be counted under the Walton Beckett grid / graticule in eyepiece should have: (a) length $> 5.0 \mu\text{m}$ and $< 3.0 \mu\text{m}$ diameter; (b) ratio of 3:1 (L : D);(c) both ends should be within the circle. Then, asbestos fiber count analysis commenced and enter in the sheet for record keeping the count fibre are used to calculated the concentration of asbestos fibre count.

Samples analysis

All analytical instruments used were calibrated before use to ensure accuracy of the data. The XRD and SEM-EDS instruments were first calibrated with a copper metal to check the corundum standard once a week every first day of the week. The image and EDS element spectra is not for the quantity. The repeatability was used except the position for copper metal and the method blank was done under the same laboratory conditions for the sample. The selectivity for image for the filtered dust brightness contrast higher contrast than less contrast package.

XRD instrument semi-quantitation was used for specified filter holder. Mineral count from the filtered dust and trapped dust samples: the dust particle size is from $10 \mu\text{m}$ to $250 \mu\text{m}$ but the threshold of particulate matter size are below $10 \mu\text{m}$. This raises concerns that human beings who reside near the former asbestos mine dumps are exposed to the dispersion/transportation of dust which is contaminated with asbestos fibres. A filtered dust samples was cut with scissors for the analysis.



Figure 3.11: One example of filtered dust sample cut with a scissor for analysis into four sizes

XRD Procedures

The samples were then stored in an air-conditioned laboratory. No sample preparation was performed for dust captured on filters as the backloading filter sample holders were used. Figure 3.12 shows a photograph of the samples prepared and mounted for XRD powder analysis.



Figure 3.12: Examples of filter and surface dust samples mounted and ready for XRD analysis and XRD instrument

XRD operational parameters

- XRD data acquisition was performed on a PANalytical Empyrean diffractometer equipped with a Cu α anode (x-ray wavelength of about 1.54 Å).
- The diffractometer was operated at an acceleration voltage of 45 kV and current of 40 mA.
- Patterns were acquired within the 2θ angle range of 10° to 100° at a step size of 0.02° . A scan of a polycrystalline silicon reference sample was run with each batch at the same measurement conditions to confirm the peak positions.

Mineral identification and analysis

The measured pattern was interpreted against reference patterns of the International Centre for Diffraction Database (ICDD). Each mineral has a unique crystalline structure and as such generates a pattern which can be used for its identification. The amount of the respective crystalline material present is estimated based on the relative peak intensities of each mineral detected. A typical example of the interpretation process of an XRD pattern is shown below:

Procedure for mineral analysis on filtered and trapped dust samples by SEM-EDS

Samples were stored in an air-conditioned laboratory. Sample preparation differed depending on whether the sample was a filter sample or a trapped dust sample. Sample stubs with double-sided carbon sticky tabs were used. Below is figure 3.13 the SEM-EDS instrument which elaborate how the samples are been analysed.



Figure 3.13: SEM-EDS instrument

Filter samples

The stub was very lightly drawn over the surface of the filter to attach particles to the carbon without lifting off any of the filter material itself.

Trapped dust samples

A section of tape containing particles was cut out with scissors and applied to the stub.

Analytical approach to SEM samples

The samples were coated with a thin layer of evaporated carbon to ensure conductivity for the electron beam in the chamber vacuum.

In the SEM, the following operating conditions were settled on:

- 15 kV
- 60 micron aperture
- 8 mm working distance
- Backscattered detector

Mineral analysis

- The spectrum for each particle is used to identify the type of mineral the particle may have come from. On occasion the morphology of the sample may aid in the identification, for example, when the sample is clearly fibrous or angular, but where particles are small, the morphology is not evident.
- Identification is aided by a database that have been developed in-house from having analysed many spectra over the course of the project. In spite of this, a mineral can at times only be broadly identified as, for example, a feldspar. The larger the particle, the more often a 'pure' spectrum is attained and identification is eased.
- After all particles analysed were identified as far as possible, each spectrum is labelled with the type of particle identified and the AZTEC software calculates the percentages.

XRF analysis preparation the surface dust samples are crushed, milled and split before the analysis can commence and surface dust; rock samples are analysed for major element analysis ($< 75 \mu$ fraction) were roasted at 1000°C for at least three hours. The XRF is used to quantify the geochemical composition of the dust particles or fibres in surface dust samples. Glass disks were prepared by fusing 1g roasted sample and 10 g flux consisting of 49.5 % $\text{Li}_2\text{B}_4\text{O}_7$, 49.5 % LiBO_2 and 0.50 % LiI at 1150°C . For control an in-house amphibolite reference material (sample 12/76) was used and one in every ten samples was duplicated during sample preparation. For trace element analysis 12 g milled sample and 3 g Lico wax were mixed and pressed into a powder briquette by a hydraulic press with the applied pressure at 25 ton. The glass disks and wax pellets were analysed by a PANalytical wavelength dispersive Axios X-ray fluorescence spectrometer equipped with a 4 kW Rh tube (Crowley, 2016).

3.5 Quality control

3.5.1 Quality control for fieldwork equipments

Quality Control (QC) is necessary for optimization of the laboratory instruments and calibration (reliability, correct readings, and known values serves of standards). Testing different parameters identify the one that gives the best results.

The single dust buckets were cleaned with distilled water then refilled with deionised water before the beginning of the fieldwork for dust sample collection (ASTM D 1739-1970).

AirCon 2-High Volume sampler (Model number F-PRO-3100) must be set up in the vertical position to maintain the rotameter in the correct position and optimised accuracy. The rotameter provided in this sampler has been tested for accuracy and is within $\pm 5\%$ of full scale. The bottom legs of the sampler opened by unfolding the lock knot and pulling the legs outwards as far as they could extend.

The largest locking collar at the bottom of the stand was loosened and pulled out; the second largest locking collar was also pulled out and the largest collar tightened.

Holding the extended section, the second largest locking collar was loosened and extended along the next section of the mast. The second largest collar was tightened and this procedure was repeated until the mast was extended to its full or required height. Care was taken to tighten each locking collar before proceeding to loosen the next. The extended mast was positioned next to the sampler. The sampler operation flow ranged from 2 to 3 LPM and constant flow capabilities ranged from 2 to 3 LPM @ pressure up to 7 psi, operating temperature range from - 20° to 45°C (-4°F to 113°F), storage temperature range from - 40° to 45°C (- 40°F to 113°F) and humidity from 0 to 95 % RH. The sampler was calibrated by the supplier once a year (AirCon 2 manual, 2016).

With regard to E-sampler (Model number 9800), the flow rate is important for the sampler for two reasons. Firstly, the flow rate must be calibrated to cut the point in sharp cyclone and the point determines the momentum of particles. The momentum of particles is a product multiplied by the mass. The entered particles in a cyclone are separated at the cut point and the velocity depends on flow rate in actual conditions. The sampler controls the flow to actual conditions to maximise the point in cyclone. The actual flow based on the ambient temperature and pressure measurements must be verified and calibrated with the flow rate. Secondly, the gravimetric 47 mm filter is used because it is important to know the volume of air sampled through the filter.

The sampler temperature should be at 24.3 °C, pressure at 101325 PA, actual flow should be at 0.012 µg/m³ and it must stabilised for two minutes; vacuum pump is 100 000 hours and it operates at the flow of 2.0 µg/m³; if the pump is unable to calibrate it means that the 0.012 µg/m³ needs to be replaced.

The purpose of cleaning of the TSP is to make sure there are no particles clogged at the top point of the sampler. The leak check, flow calibration, inlet cleaning and alarm log are checked every month. The pump check and calibration are done every two months, pump filter and purge filter are done yearly and battery memory check is done every five years.

3.5.2 Quality control for laboratory instruments and apparatus

Quality Assurance (QA) refers to the specific methods, steps and processes to ensure the quality of the laboratory instruments. Chain of custody validation and verification to calculate the matrix (errors) must be carried out in order to identify the errors and check precision, accuracy and percentage recoveries.

Settleable dust rates (mass concentration) analysis for the quality control is required. First, the weigh mass must be calibrated before use and evaporation dishes should be checked to sample if they are clean. The laboratory's cleanliness should be checked to ensure no dust on the laboratory desks before the filtration process starts. The personal protection clothes must be worn during laboratory working hours from beginning to end. Gloves, boots, goggles, asbestos dust masks and laboratory coat must be worn at all times. The following apparatus must be cleaned: beaker, connector, Buchner funnel, pipe and the vacuum pipe.

SEM analysis quality control is carried out as follows: first check precision etching coating system which will provide planar polish and copper carbonated coated, cross-section capabilities in the SEM instrument in order to match the sample preparation expectations. The SEM image must be intricate to allow a better understanding of the image details and the grains relationship orientation or dislocations and strains across boundaries. The grain boundaries are prepared when the SEM instrument verses on an electro-polish technique. The SEM instrument is able to reproduce results over a large surface area or scale. The SEM evaluation is based on the sample prepared with the instrument post planar milling; then the SEM results show polished and coated precision and are maintained as far out 600 μm from the centre of the sample.

Mineralogy (XRD) analysis requires that a riffle splitter is placed on a plastic sheet on the laboratory floor. The two dishes are placed under the splitter and the solid sample is poured into the splitter so that it is split between the two dishes. Samples from two dishes are then transferred into sample bags. Sample bags for the same samples are labelled with the same number to indicate that they are duplicates.

Geochemistry (XRF) analysis as described by Cloete and Truter (2001) was adopted for this study. Analysis for major and trace elements in solid samples was performed using PAnalytical Axios X-ray Fluorescence spectrometer. For major elements analysis, the milled sample (< 75 μ fraction) was roasted at 1000°C for at least three hours to oxidise Fe²⁺ and S, and to determine the loss on ignition (L.O.I).

Glass disks were prepared by fusing 2 g roasted sample and 8 g flux consisting of 35 % LiBO₂ and 64.71 % Li₂B₄O₇ at 1050 °C. For trace elements analysis, 12 g milled sample and 3 g Hoechst wax were mixed and pressed into a powder briquette by a hydraulic press with the applied pressure at 12 tons. The glass disks and wax pallets were analysed on a PAnalytical Axios X-ray Fluorescence spectrometer equipped with a 4KW Rh tube.

3.6 Summary

Asbestos mine dumps heights are between 20 m and 50 m and they are situated near human settlements. None of the asbestos mine dumps situated in Mpumalanga Province are rehabilitated, which is a concern, and in Limpopo Province dump B is fully rehabilitated and dumps A, C, D and E are partially rehabilitated. These still pose a risk of exposure to asbestos dust from the mine dumps. The South African Dust Control National Regulation no 827 of 2013 was used to collect settleable dust samples. Since settleable dust does not fall into the dust bucket unit, surface dust samples were also collected on the ground surface near the single dust bucket unit. Trapped dust samples were collected on old units, windows and car windscreens using sticky tape and the SEM was used to determine the morphology. The other supporting equipment for this research was the AirCon 2 high volume which helps to determine particle fibre count and SEM; the E-sampler which operates/functions according to two principles (lighter scatter and gravimetric) and determines the wind speed.

The instrument used to determine oxides of silicate minerals and silicate mineral was XRF, the mineralogy data was XRD and morphology was determined using SEM-EDS. The filtered dust samples analysed by XRD and SEM were prepared by coating with carbonate and surface dust samples were analysed for XRF.

The particle fibre counts were determined by the use of the phase contrast microscope whereby fibres from each filter dust substrate from the AirCon 2 – high volume and E-samplers were counted physically.

Quality control was done by XRF, XRD and SEM calibration according to the instruments methods, validation and by identifying the errors from data. The laboratory facilities were cleaned before the analysis.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Introduction

The chapter contains the results of the settleable dust rates after a comparative study undertaken during the piloting phase, the application of the official settleable dust rate method in the study area, the characterization of the dust sample on the exposed filter, the validation of the asbestos mineral count method using the asbestos fibre count method and the novelty of the study.

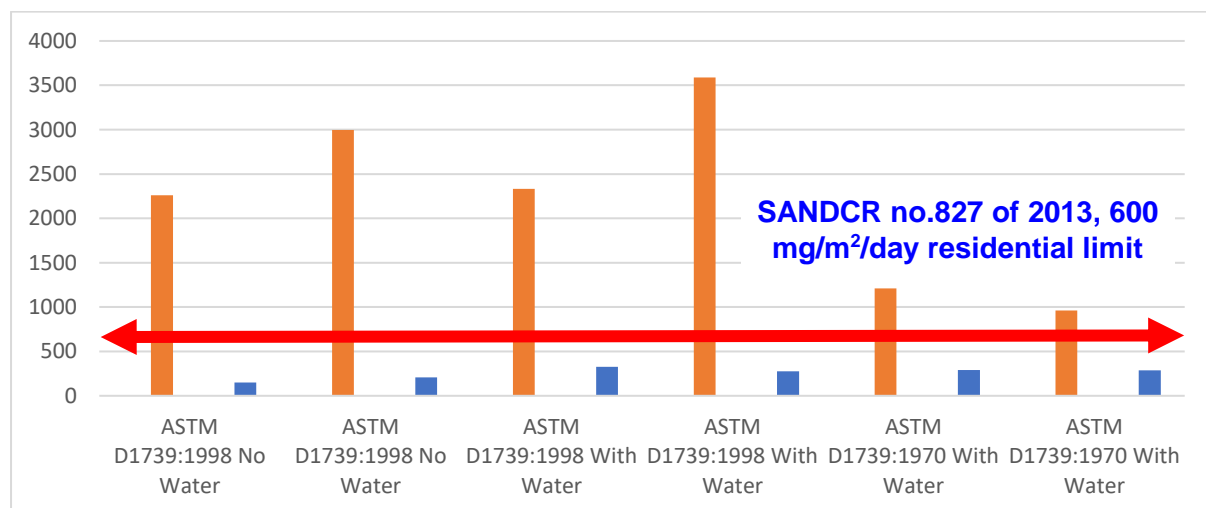
4.2 The pilot study data

A pilot study that preceded the current study was conducted by the researcher for the purpose of comparing the performances of two commonly used settleable dust methods by the mining companies and the results are presented in Figure 4.1. Two pilot study areas were selected, Mpumalanga Province characterized by asbestos mining and the North West Province, which serves as a control and was a known platinum group of metals mining region. The data from Mpumalanga Province shows very high dust deposition when compared to the data from the North West Province irrespective of the method used. Both methods show the presence of water in the holding single bucket unit plays a significant role with more dust being deposited than when water was absent. Also, the presence of an algaecide solution medium made the sample mixture easier to filter and led to higher dust retention yields (Figure 4.2). There was no algaecide solution added in the buckets units and a solid crust-like material at the base and dust sample could not disaggregate from algae and other non-dust material when water was added during the filtration process. The filter pores got easily blocked and that may explain the relatively low settleable dust rate levels when an algaecide was absent. The results also shows that the where 5% copper sulphate (CuSO_4) and 5% sodium hypochlorite (NaOCl) were used as algaecide solutions, the CuSO_4 solution yielded slightly higher mass concentration of settleable dust than NaOCl solution. Loans (2007) study reported 5.0% NaOCl algaecide solution to be forming a solid crust mixture that was made of dust materials and some algae. However, in situations where copper was one of the analytes, using CuSO_4 may not be appropriate due to possible contamination.

The first and second sets of data show that the ASTM D 1739:1998 was the most efficient method in dust deposition or collection with dust rates of two times or more than the ASTM D1739:1970 method. The third set of data shows both methods to be performing in the same way, however, the fourth set of data reversed the performance trends with the ASTM D 1738:1970 method performing about two times more than the other method. The settleable dust rates data from the North West Province also shows the ASTM D 1739:1998 method to perform better. While the ASTM D: 1739:1998 method performed better in dust collection, it is not governed by legislation and is not recommended by Department of Environment, Forestry and Fisheries (DEFF).

No clear reasons could be found in the literature why this method was not favoured by the government. However, this researcher suspects that it could be due to the different windshield designs that makes it difficult to compare or regulate it (see Figure 2.6 on page 70 in Chapter 2).

Despite determining that the ASTM D1739:1998 method performed better in dust deposition / collection, the next phase of the study was undertaken using the ASTM D1739: 1970 method, which is the officially recommended in South Africa (NDCR 827, 2013).



Note: Orange: Mpumalanga Province; Blue: North-West Province = Control

Figure 4.1: Comparison of maximum settleable dust rates (mg/m²/day) between ASTM D1739:1998 No Water and ASTM D1739:1980 With Water for Mpumalanga and North-West Provinces

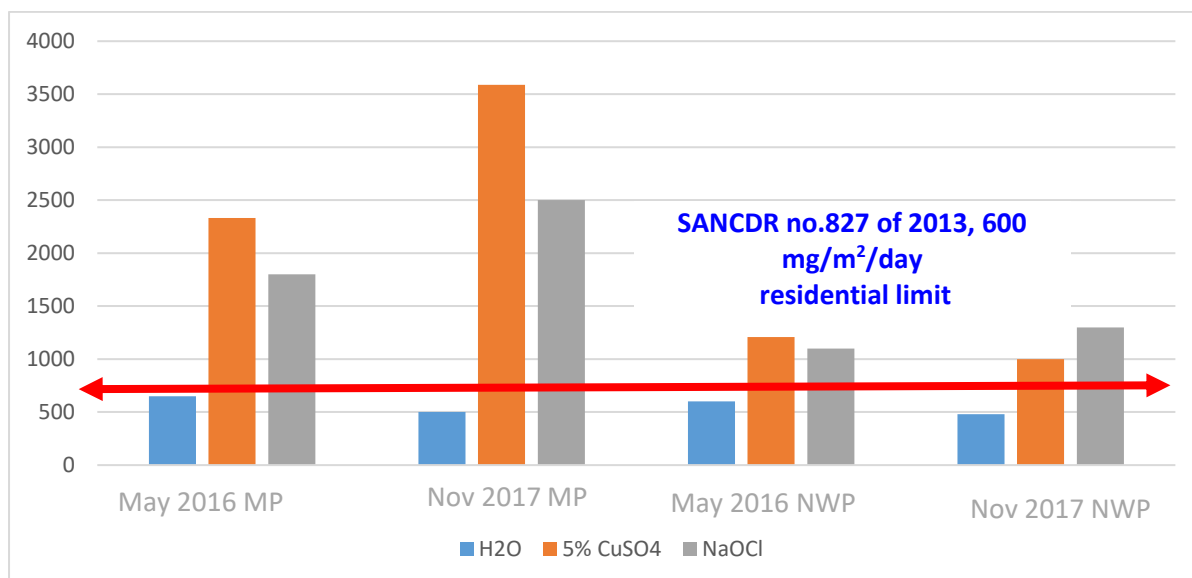


Figure 4.2: Comparison between With Water (H₂O), 5% Algaecide (CuSO₄) and NaOCl

4.3 Settleable dust results

4.3.1 Settleable dust results for Limpopo and Mpumalanga provinces from April 2016 to June 2017

The National Environmental Management: Air Quality Act no.39 of 2004 states that the acceptable settleable dust rate measured using ASTM D1739:1970, within the residential limit should not exceed 600 (mg/m²/day, 30 Days) (30 days means the duration which the exposed bucket units are deployed onsite before exchanging them with unexposed buckets) on average and the exceedances that may occur should not for more than 2 months within the same year.

Figure 4.3 shows monthly settleable dust rates from April 2016 to June 2017 for Mpumalanga Province.

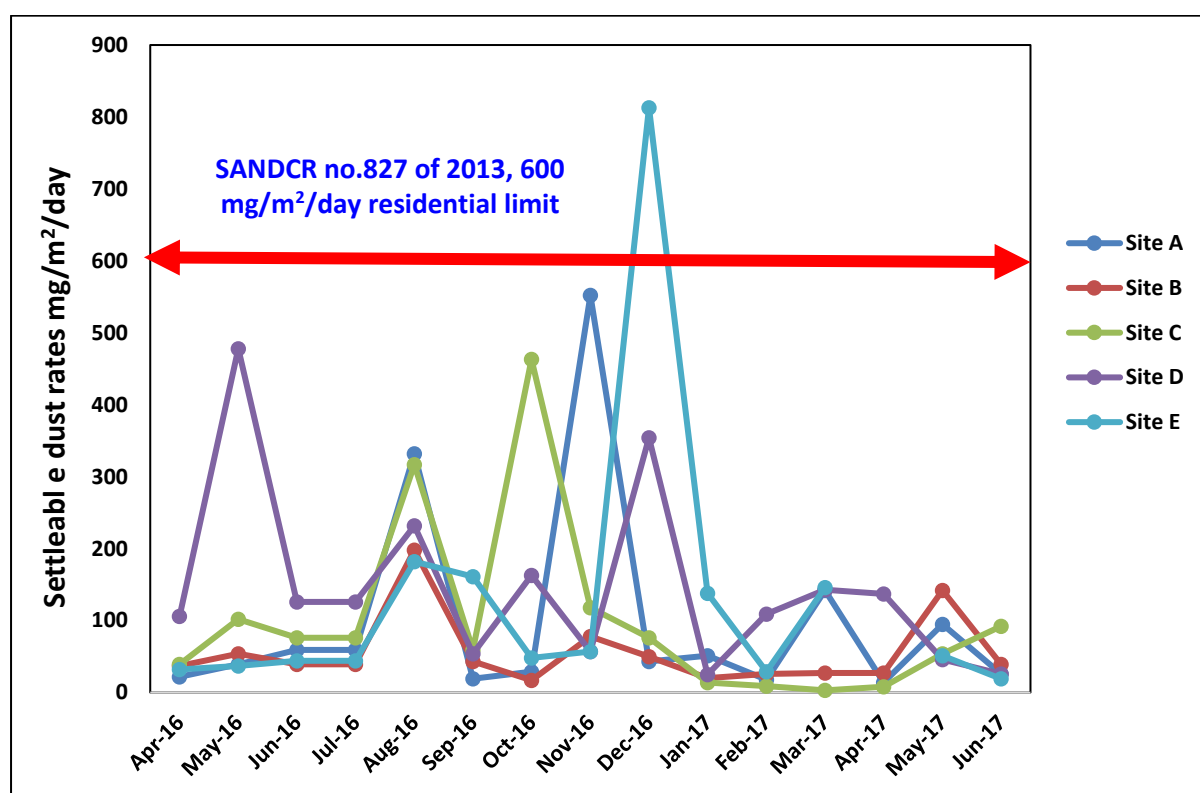


Figure 4.3: Settleable dust rates from April 2016 to June 2017 for Mpumalanga Province

All the settleable dust rates are below the residential limit of 600 mg/m²/day, except for the 813 mg/m²/day, which was measured on a sample collected at site E in December 2016, see Figure 4.3. This once-off episode was negligible because the minimum requirement of the standard is two random exceedances in a year (NDCR No: 827, 2013). The first three high settleable dust rates that are below the 600 mg/m²/day limit in decreasing order were measured at site A in November 2016, site C in October 2016 and at site D in May 2016. The data do not show any trends that could be associated with the seasons. All the asbestos mine dump sources around the study areas are not rehabilitated.

Figure 4.4 shows the monthly settleable dust rates from April 2016 to June 2017 for Limpopo Province.

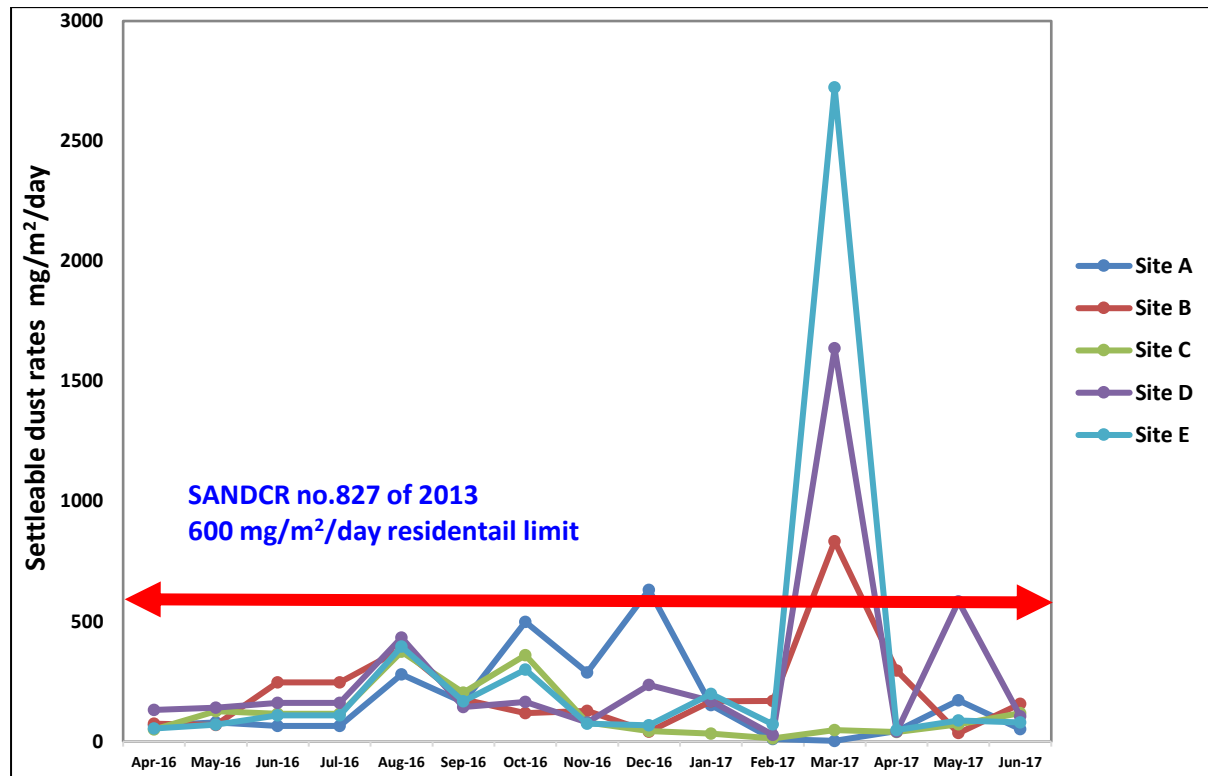


Figure 4.4: Settleable dust rates from April 2016 to June 2017 for Limpopo Province

The settleable dust rates results for Limpopo Province are below the residential limit of 600 mg/m²/day, except for 2724 mg/m²/day from site E, 1638 mg/m²/day from site D and 834 mg/m²/day from site B in March 2017. While the three exceedances have been measured in the same month, but from different sites, the data remain negligible according to the minimum requirement of the standard (NDCR No: 827, 2013). Again, there is no direct relationship between the dry and windy season with high settleable dust rates as observed in the data from a parallel study in Mpumalanga Province. The occurrence of the three exceedances is of concern since the three sites have been rehabilitated with site B being fully rehabilitated, sites D and E being partially rehabilitated. Data measured at site E in August, October and December 2016 are also high but within the national limit.

Figure 4.5 shows a summary of the highest settleable dust rates during the monitoring period and the sites which experience exceedances at sites E, D and B in Limpopo as well as E in Mpumalanga Provinces.

While the results for other sites are relatively low when compared to the residential limit, all efforts that could reduce the human exposure should be undertaken due to the possible danger that may emanate from some minerals present in the sample.

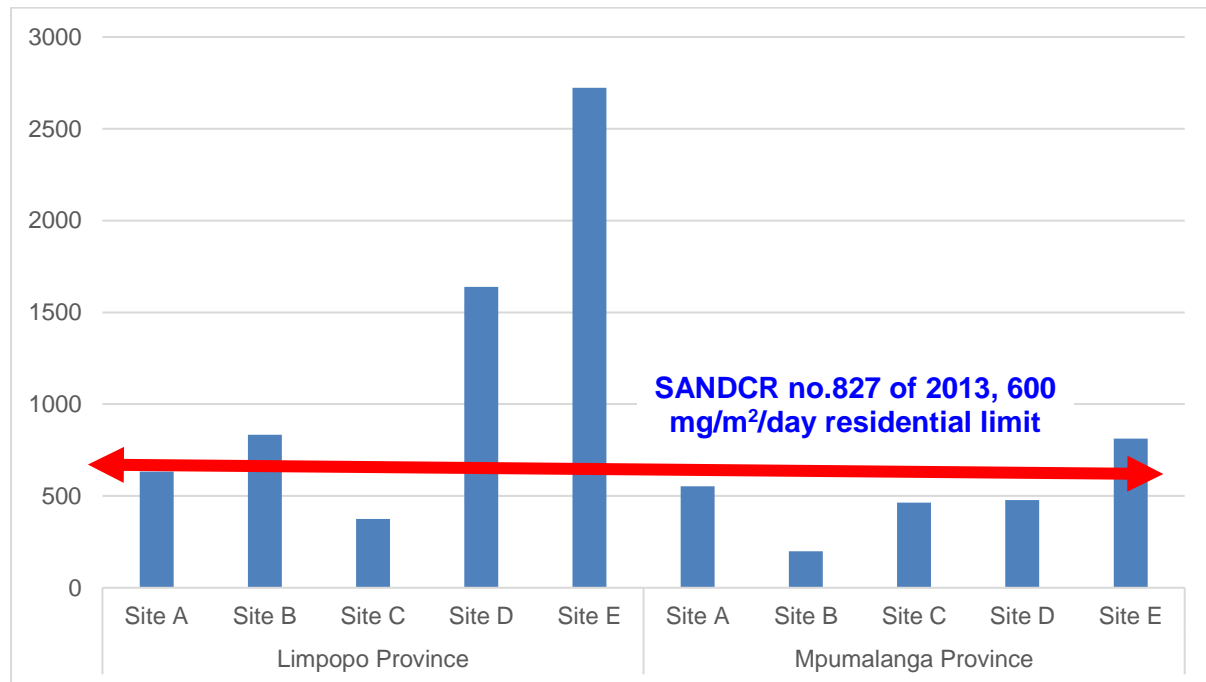


Figure 4.5: A summary of the maximum settleable dust rates

4.3.3 Images of the filtered settleable dust samples before characterization

Figure 4.6 and 4.7 shows the first screening of the filtered settleable dust samples with SEM images with magnification from 2 mm to 750 µm. The crystal minerals are visible on the images and the researcher suspects that the white colored minerals are part of the asbestos material that is embedded around these minerals (See Appendix B for more SEM-EDS images).

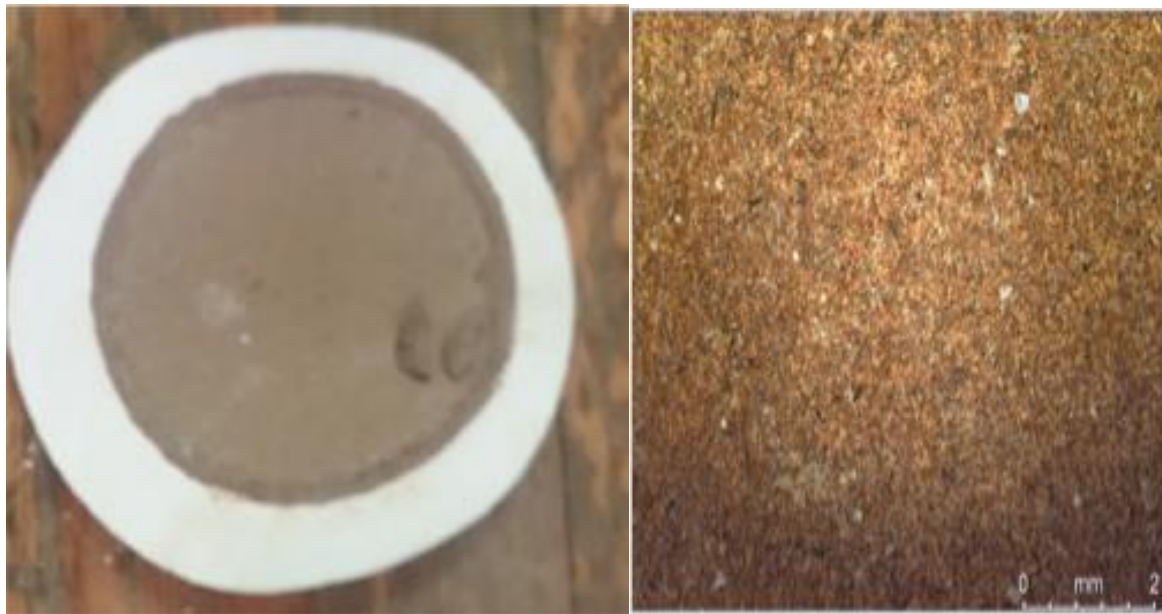


Figure 4.6: SEM images of the filtered dust samples for Limpopo Province

Limpopo Province filtered samples colours for Sites A, C, D, E which are light-brown and Site B is brown. The magnification of the scanned images is 2 mm and 500 μm . Site A, B, C, D and E shows short fibre but the concern with short fibres is that they are suspended in the air easily and are inhaled unknowingly.

Figure 4.7 shows that the Mpumalanga Province filtered dust samples which are between green, black, light brown and grey colours where silicate and crystal are not visible. The magnification used for the SEM image is 2 mm which shows whitish for Site A, yellow gold for Site B, dark-brown for Site C, brown plus white for Site D and Site E is whitish plus brown. The SEM images from the filtered dust samples colours are light brown, brown whitish and yellow-golden colour and the image shows that suspicion curved, spiral and straight line fibres shapes and at the magnifications from 2 mm to 750 μm . The geology formation of Mpumalanga Province is Tjakaastad and Komatities Supergroup and the asbestos mineral occurs in veins of the rock crack seams. Chrysotile asbestos mineral from the serpentine group was mined in Mpumalanga Province and the scan image results confirm the similar colour to the whitish/greyish chrysotile asbestos mineral. Chrysotile asbestos mineral produce long fibre which was also commercially used as a product to manufacture brake pads for cars, roofing and used as a mixed to build houses that's why most of the old infrastructure shows evidence of asbestos mineral.



Figure 4.7: SEM-EDS images of the filtered dust samples from Mpumalanga Province

4.3.2 Meteorological data interpretation

4.3.2.1 Meteorological data for Mokopane and Nelspruit regions (April 2016 until June 2017)

Meteorological data provide values for average temperature, rainfall, humidity and monthly predominant wind direction, wind speed and atmospheric stability, which affect the settleable dust rates concentration (was or has been) at a particular location. Meteorological conditions were the most important parameter which influences dispersion and deposition of fugitive dust. The traditional wind rose indicates the frequency of directions from which the wind was blowing as well as the wind speed for each direction (South African Air Quality Information System, 2010). Meteorological data from South African Air Quality information system, South African Weather Services and Municipalities (Kwata, 2014).

The meteorological data comprising of monthly averaged temperature, humidity, rainfall and wind velocity for Mokopane and Nelspruit were obtained from South African Weather Services (SAWS, 2016; SAWS, 2017).

SAWS monitoring stations that are in close proximity to the five (5) air quality monitoring sites in Limpopo province and five (5) sites in Mpumalanga province are located in Mokopane (S 24° 19' 60", E 29° 00' 60") and in Nelspruit (S 25° 50 '3", E 30° 91' 10") respectively. The meteorological parameters were arranged according to four (3) seasons: June, July and August 2016 (Winter), September, October and November 2016 (Spring) and June 2017 (Winter) See more wind roses graphs in Appendix A.

Tables 1 and 4 (See Appendix A) show the average meteorological parameters, i.e. temperature (maximum and minimum), humidity, rainfall and wind velocity around Mokopane area. From Table 1 (See Appendix A) and from Figure 4.6 to 4.8 show the average monthly meteorology parameters for Mokopane station in Limpopo Province and Nelspruit station in Mpumalanga Province.

The average temperature maximum for Mokopane, location of the nearest meteorological station for all the five dust monitoring sites situated in Limpopo Province, range from 23.4 °C to 32 °C. The average temperature for Mokopane shows the highest in October 2016 with 32 °C, November 2016 with 31.4 °C, and December 2016 with 31.8 °C during spring season and there are exceedances in the residential limit of 600 mg/m²/day for the settleable dust rates and March 2017 with 32 °C which is during autumn season. The lowest temperature occurs in July 2016 with 23.4 °C where the settleable dust was also low during dry season where it was acceptable that settleable dust rates should be high. The average temperature minimum for Mokopane ranges from 5 °C in July 2016 to 18.7 °C in February 2017. All the average wind speed (0.5 m/s in June 2016 to 1.9 m/s in October and November 2016) are below the maximum wind speed of 5 m/s which have the influence of dust generation from wind blowing from the asbestos mine dumps to the nearby local communities.

The rainfall in Mokopane from November 2016 with 72 mm to December 2016 with 61 mm, which are both the highest and the lowest average rainfall, occur in May 2016 with 5 mm and June 2016 with 4 mm and settleable dust rates in May and June 2016 are also low and below the residential limit of 600 mg/m²/day. The highest settleable dust rate occurs in December 2016.

However, from the average temperatures, December 2016 experienced the highest average temperature where settleable dust rates were accepted to be low because of low windblown dust because the asbestos mine dumps will be wet. During rainy season wet surfaces and wet mine dumps reduce settleable dust generation from asbestos mine dumps. Settleable dust rates in March 2017 were the highest; it could be due to the fact that in autumn season, there was wind blowing and unpaved roads with heavy daily traffic produces dust. The average humidity for Mokopane ranged from 50.7 % in October 2016 to 74.1 % in February 2017. The highest humidity is 74.1 % during which time the settleable dust rate is low (at 50.7 % which is the lowest). The settleable dust rates in October 2016 and February 2017 are below the residential limit of 600 mg/m²/day (See Appendix A table 1). The low humidity reduces visibility and high humidity causes dust mite population and mould colonies (Arlian et al., 1999).

Wind roses are defined as radial graphs for a specific location that summarises the occurrence of winds by direction and speed (Sekonya, 2009). Different categories of wind velocity are represented by different colours: yellow represents wind velocity of 0.1 to 1.5 m/s, purple represents wind velocity of 1.5 to 3.0 m/s, red represents 3.0 to 5.0 m/s, turquoise represents 5.0 to 8.0 m/s, bright green represents 8.0 to 11.0 m/s and blue represents wind velocity of greater than 11.0 m/s. The length of each speed tells the frequency of wind coming from a particular direction. The circle in the centre indicates calm winds (SAWS, 2016; 2017).

Figure 4.8 shows the monthly average wind roses for June, July and August 2016 (winter season) at the Mokopane weather station, also next to the location of sampling sites A, B,C,D and E. The center represents the calm and windless environmental conditions at 42.9 %, 36.0 % and 25.8 %. The predominant wind direction around the study area in decreasing order are NW, NNW and WNW with wind speed of 5 m/s. Since sites A, D and E are located in the path of the predominant wind direction and highest wind speed, there will experience or received more contaminated dust. Human settlements located in these areas are vulnerable and will be heavily impacted. In contrast, sites B and C experience windy conditions of less than 5 % thus receive less dust. Sites B and C are the remaining windy conditions less impacted which are all below 5%.

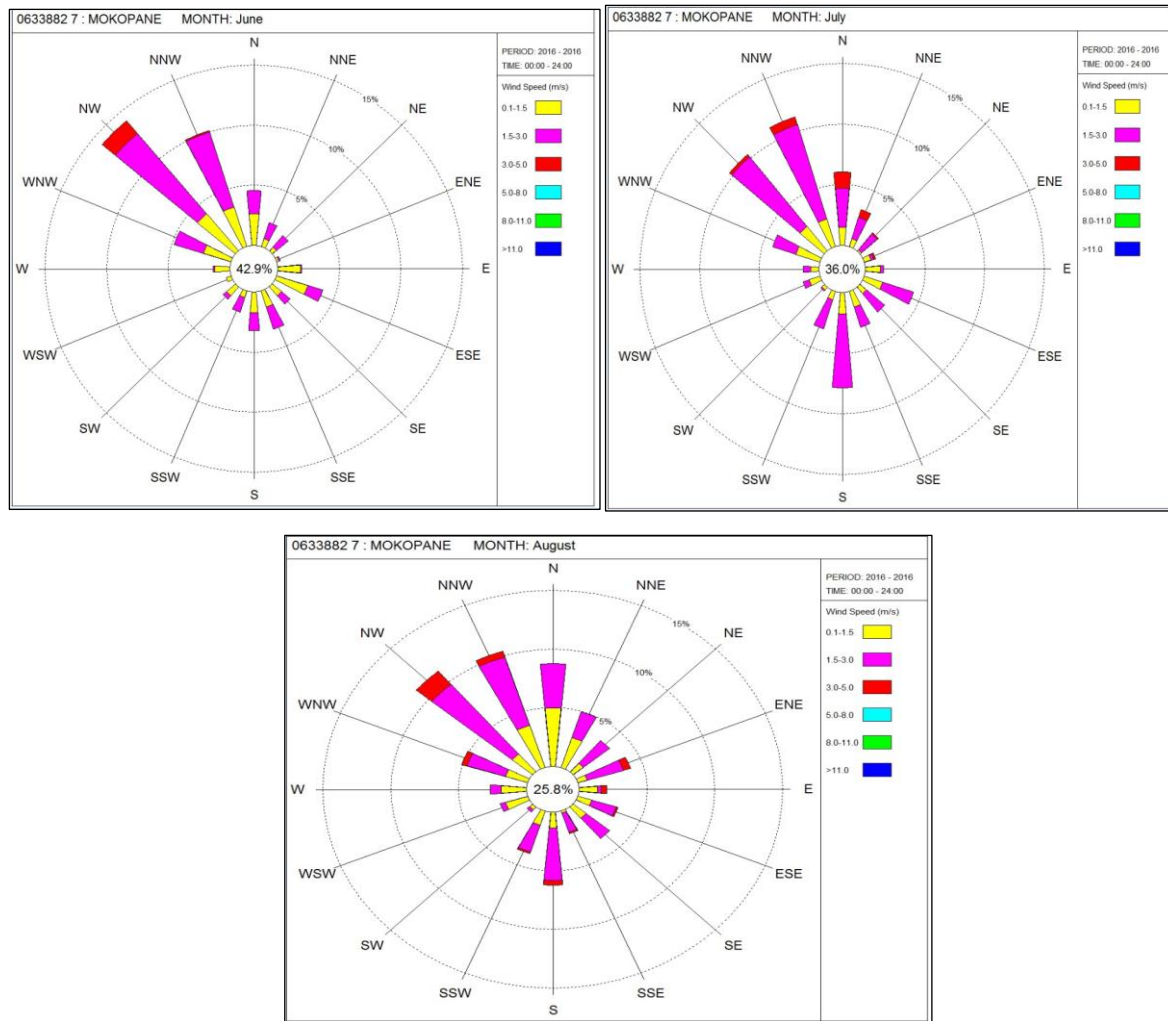


Figure 4.8: Monthly average wind rose for Mokopane for June, July and August 2016 (winter season)

Figure 4.9 shows the monthly average wind roses for September, October and November 2016 (winter season) at the Mokopane weather station, also next to the location of sampling sites A, B, C, D and E. The center was the calm and windless environmental conditions at 8.9 %, 9.8 % and 13.8 %. The predominant wind direction around the study areas are in decreasing order N, NNW and NW at wind speed of 8 m/s. Since sites A, D and E are located the path of predominant wind direction and highest, there will experience or receive more contaminated dust. Human settlements located in these areas are vulnerable and will be heavily impacted. In contrast, sites B and C experience windy conditions of less than 5 % thus comparatively receive less dust. Sites B and C are the remaining windy conditions less impacted which are all below 5 %.

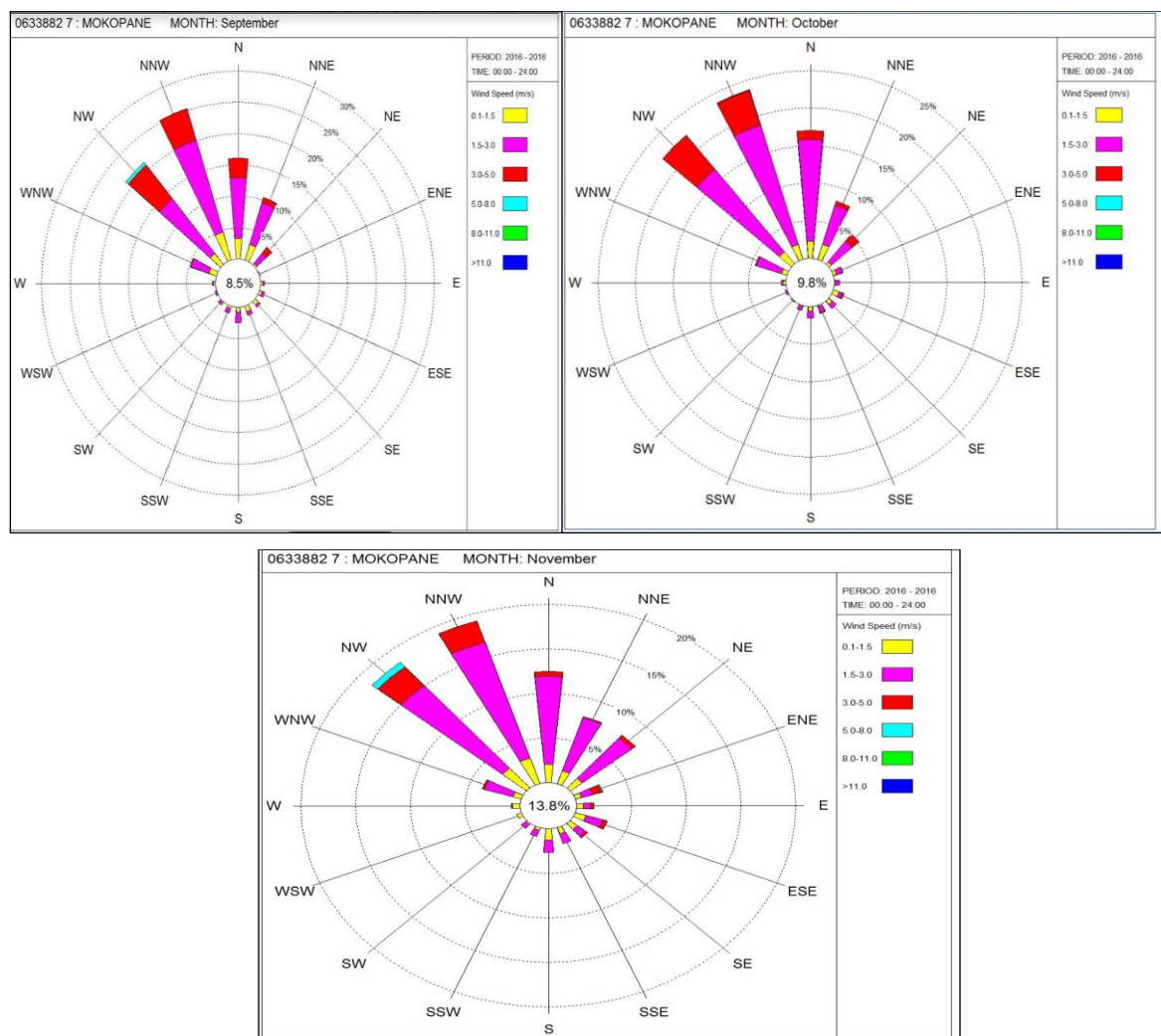


Figure 4.9: Monthly averaged wind rose for Mokopane for September, October and November 2016(spring season)

4.3.4.2 Meteorological data for Mokopane and Nelspruit regions (April 2016 until June 2017)

The monthly average temperature for Nelspruit region at 08h00 ranged from 21.7⁰C to 28.5 ⁰C from the nearest meteorological station in Nelspruit. See Appendix A table 2 shows the highest average temperature is 28.5 ⁰C in March 2017 autumn season with 28.5 ⁰C and the lowest in 21.7 ⁰C in July 2016 dry season. Both March 2017 and July 2016 low settleable dust was recorded. During the dry season high settleable dust rates are acceptable but from the average temperatures, it was clear that influence of temperatures was low to settleable dust rates generation and the settleable dust rates in March 2017 and July 2016 were below the residential limit of 600 mg/m²/day (See Appendix A Table 2).

The monthly average rainfall for Nelspruit ranged from 1.8 mm in September 2016 to 198.6 mm in December 2016. The highest average rainfall in Mokopane region was in December 2016 with 198.6 mm and the lowest was in September 2016 with 1.8 mm. Settleable dust rates in September and December 2016 are below the residential limit of 600 mg/m²/day and show a peak which is because of low rainfall but an increase in the retaining dust in the bucket unit.

The monthly average humidity for Nelspruit region ranged from 54.5 % in August 2016 to 79.1 % in February 2017. The highest humidity in Nelspruit region is 79.1 % and the lowest is 54.5 %. Settleable dust rates during the dry season which is August 2016 were below respectively. In the ESE direction, the winds blow 5 and 15 % of 24 hours at 5 to 10 to 5 and 3.0 to 5.0 m/s respectively. Strong winds also blew from W and WS. Winds are calm at 16.9 % of the time.

Figure 4.10 shows the monthly average wind roses for June, July and August 2016 (winter season) at the Nelspruit weather station, also next to the location of sampling sites A, B, C, D and E. The center represents the calm and windless environmental conditions at 15.3 %, 10.5 % and 14.5 %. The predominant wind direction around the study area in decreasing order are E, ENE, NE and WNW, W and WSW with wind speed between 8 and 11 m/s. Since sites D and E are located in the path of the predominant wind direction and highest wind speed, there will not experience or received more contaminated dust. Human settlements located in these areas are vulnerable and will be heavily impacted. In contrast, sites A, B and C experience windy conditions of less than 5 % thus receive less dust.

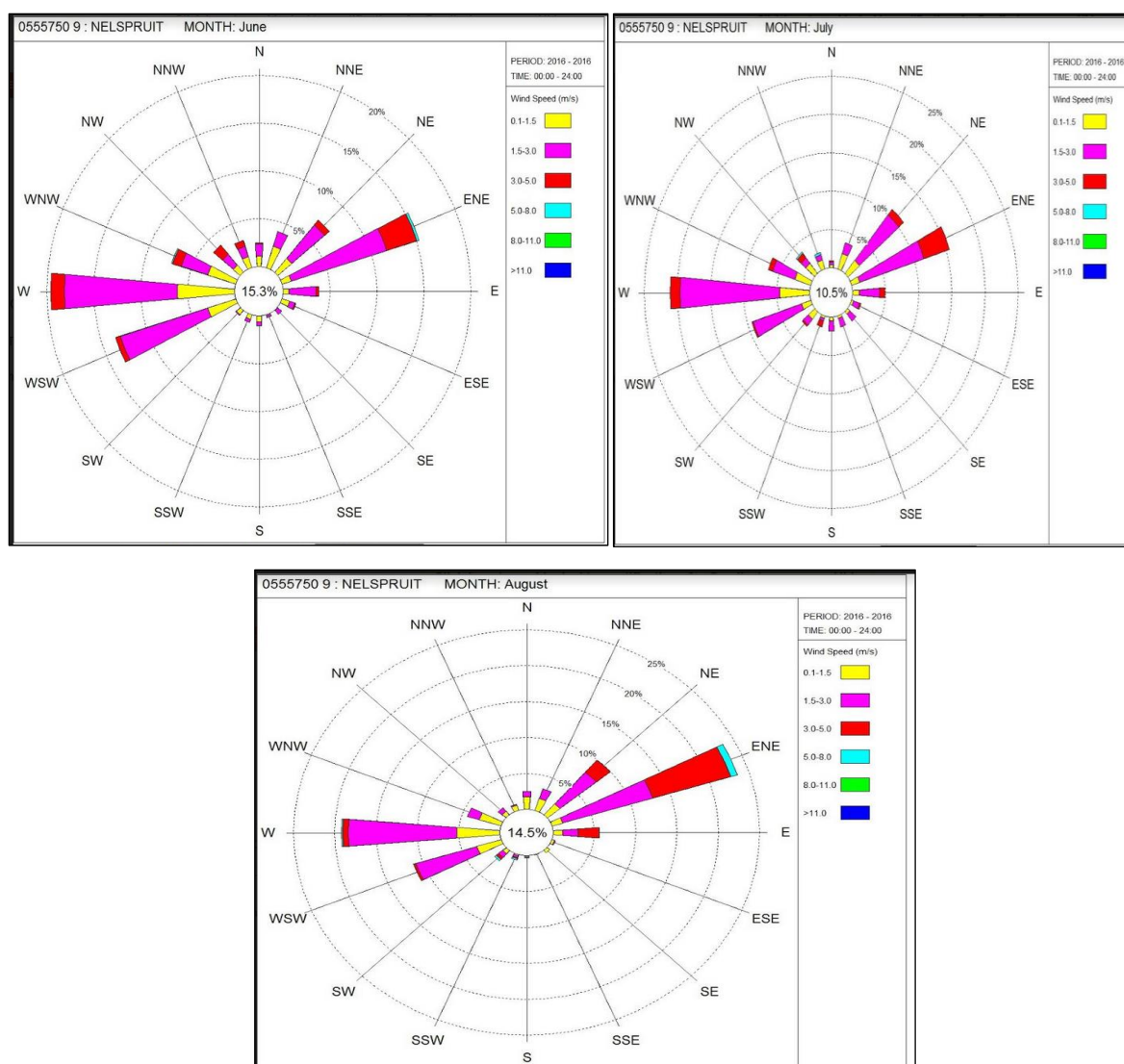


Figure 4.10: Monthly average wind direction for Nelspruit for June, July and August 2016(winter season)

Figure 4.11 shows the monthly average wind roses for September, October and November 2016 (winter season) at the Nelspruit weather station, also next to the location of sampling sites A, B, C, D and E. The center represents the calm and windless environmental conditions at 10.1 %, 7.8 % and 9.3 %. The predominant wind direction around the study area in decreasing order are NE, ENE and E with wind speed between 8 and 11 m/s. Since sites D and E are located in the path of the predominant wind direction and highest wind speed, there will not experience or received more contaminated dust. Human settlements located in these areas are vulnerable and will be heavily impacted. In contrast, sites A, B and C experience windy conditions of less than 5 % thus receive less dust.

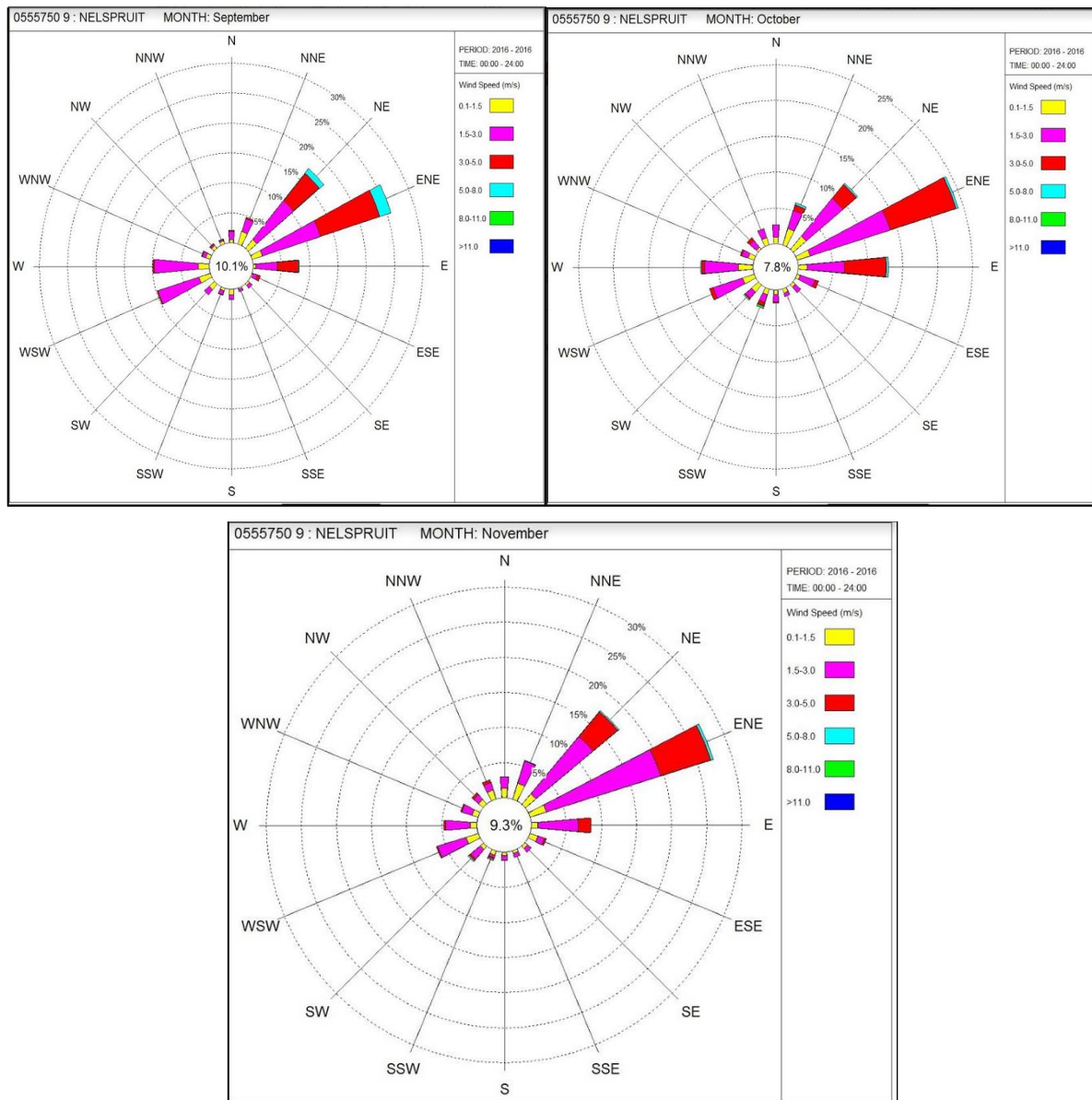


Figure 4.11: Monthly average wind direction for Nelspruit for September, October and November 2016 (spring season)

4.4 Prediction of falling Settleable dust from the mine dumps

Table 4.1 show the predication time of the settleable dust falling from mine dumps to near human settlements. The data from Mpumalanga Province shows that dust particles with diameters of 1.0 μm , 5.0 μm and 10 μm respectively will take 134.7 hours, 5.4 hours and 1.4 hours of time to settle on the ground when they roll down at a 35 m high asbestos dump under windless conditions. The calculations were make using the model developed by the DustWatch (2015). The dust particles with the same diameter sizes rolling down from a 20 m high asbestos dump under windless conditions will respectively take 77.0 hours, 3.1 hours and 0.8 hours for Limpopo Province. The data shows that smaller particles spend more time than larger particles in the air before they can settle in the ground; hence particles with 1.0 μm diameters have longer retention times in air than particles with 10 μm diameter sizes.

Table 4.1: The measurement of the rate of a settling airborne dust

Province	Dump	Diameter (μm)	Height (m)	Reynolds number (Re)	Terminal Velocity (m/s)	Seconds (Secs)	Minutes (Mins)	Hours (Hrs)
MP	A	1.0	35	0.000003346	0.0000722	484764.5	8079.4	134.7
		5.0	35	0.00042	0.0018	19444.4	324.1	5.4
		10	35	0.003346	0.00722	4847.7	80.8	1.4
LP	A	1.0	20	0.000001912	0.0000722	2770008.3	4616.8	77.0
		5.0	20	0.00024	0.0018	11111.1	185.2	3.1
		10	20	0.001912	0.00722	2770.1	46.2	0.8

4.5 Characterization of filtered settleable dust samples

4.5.1 The geochemistry data for Limpopo and Mpumalanga Provinces

The April, July, September 2016 and January, April, July 2017 results captured in Tables 4.2 to 4. confirm the dominance of the silicate minerals within the study area. The oxide of minerals that exist in high concentrations were silicon oxide (SiO_2), aluminium (II) oxide (Al_2O_3), iron (III) dioxide (Fe_2O_3) and magnesium oxide (MgO). The other minerals that were detected were titanium oxide (TiO_2), manganese oxide (MnO), calcium oxide (CaO), sodium oxide (Na_2O), potassium oxide (K_2O), phosphorus trioxide (P_2O_5) and chromium III oxide (Cr_2O_3).

Table 4.2: Geochemistry (XRF) results (wt. %) for Limpopo Province for April, July and September 2016

April 2016						July 2016					September 2016				
XRF	Site A	Site B	Site C	Site D	Site E	Site A	Site B	Site C	Site D	Site E	Site A	Site B	Site C	Site D	Site E
SiO ₂	64.22	46.61	47.23	65.99	56.87	70.21	85.09	69.31	32.27	33.57	69.52	60.06	46.23	63.51	56.59
Al ₂ O ₃	10.17	5.84	5.86	7.33	7.63	0.26	0.28	0.76	0.06	0.05	10.49	5.57	6.08	8.67	9.19
Fe ₂ O ₃	9.23	35.32	33.67	11.47	15.11	7.84	5.46	8.69	1.82	1.62	6.33	25.38	35.48	11.87	14.79
MgO	3.1	1.5	2.21	4.18	2.68	0.100	0.015	0.116	0.142	0.101	1.92	0.58	1.48	1.52	3.59
MnO	0.245	1.39	1.41	0.296	0.45	6.14	3.44	7.33	9.74	6.73	0.149	0.571	1.23	0.346	0.391
CaO	3.93	1.45	2.56	3.95	6.26	7.83	0.36	4.19	41.10	42.42	2.94	0.58	1.4	1.77	5.24
Na ₂ O	0.89	0.28	0.31	0.53	0.64	3.19	0.38	5.64	0.22	0.02	0.93	0.39	0.26	0.39	0.75
K ₂ O	1.67	0.92	0.93	1.05	1.3	0.93	0.82	1.06	<0.01	<0.01	2.18	1.7	0.94	1.46	1.36
TiO ₂	0.87	0.68	0.67	1.53	1.9	0.42	1.27	0.82	0.03	0.03	0.67	0.27	0.72	1.62	1.67
P ₂ O ₅	0.114	0.214	0.135	0.122	0.197	0.051	0.035	0.122	0.018	0.020	0.218	0.15	0.237	0.273	0.227
Cr ₂ O ₃	0.147	0.039	0.058	0.2	0.183	0.100	0.136	0.049	1.49	1.34	0.073	0.016	0.046	0.053	0.177
LOI	5.11	5.49	4.73	3.19	6.32	2.79	3.30	1.72	12.04	12.73	4.54	4.52	6.06	8.63	6.12
Total	99.7	99.73	99.78	99.84	99.54	99.86	100.57	99.81	98.76	98.53	99.96	99.79	100.16	100.11	100.1

The silicates minerals are oxides for SiO₂ ranged from 32.27 wt. % to 70.21 wt. %, 0.05 wt. % to 10.17 wt. % for Al₂O₃, Fe₂O₃ ranged from 1.62 wt. % to 35.48 wt. % and MgO ranged from 0.58 wt. % to 4.18 wt. %. Minor trace levels of metal oxides were also detected and have intermediate rock composition for example TiO₂, MnO, CaO, Na₂O, K₂O, P₂O₅ and Cr₂O₃.

Table 4.3: Geochemistry (XRF) results (wt. %) for Limpopo Province for January, April and January 2017

January 2017						April 2017					July 2017				
XRF	Site A	Site B	Site C	Site D	Site E	Site A	Site B	Site C	Site D	Site E	Site A	Site B	Site C	Site D	Site E
SiO ₂	61.23	55.36	47.32	59.74	53.32	54.64	54.53	58.92	66.63	58.39	70.76	56.85	46.61	59.00	54.06
Al ₂ O ₃	12.86	6.09	7.7	10.51	10.08	10.38	5.71	8.2	8.3	6.31	8.90	4.13	5.84	8.28	8.98
Fe ₂ O ₃	10.02	27.97	31.91	10.29	12.27	10.33	28.21	16.34	8.71	14.1	7.62	32.72	35.32	12.39	15.58
MgO	1.83	0.83	1.39	1.65	2.35	3.0	0.79	1.91	4.92	2.14	1.50	0.50	1.50	1.85	3.69
MnO	0.197	0.442	0.639	0.323	0.279	0.25	0.421	0.611	0.215	0.387	0.324	0.622	1.39	0.344	0.443
CaO	2.93	1.06	1.35	2.93	7.31	6.52	1.37	4.34	4.44	8.0	2.82	0.37	1.45	3.20	6.01
Na ₂ O	0.57	0.37	0.33	0.57	0.56	0.9	0.56	0.22	0.74	0.57	0.74	0.35	0.28	0.39	0.77
K ₂ O	1.66	1.07	1.19	1.8	1.87	1.44	0.98	1.41	1.31	1.11	1.96	1.33	0.92	1.42	1.33
TiO ₂	0.97	0.72	0.71	1.22	0.96	1.01	0.78	0.93	0.92	1.8	1.06	0.22	0.68	1.45	1.75
P ₂ O ₅	0.148	0.205	0.225	0.362	0.31	0.134	0.233	0.112	0.098	0.16	0.066	0.116	0.214	0.370	0.174
Cr ₂ O ₃	0.085	0.028	0.042	0.047	0.074	0.077	0.031	0.039	0.189	0.231	0.061	0.017	0.039	0.051	0.331
LOI	7.43	5.87	7.21	10.46	10.71	11.03	5.98	6.76	3.3	6.63	3.92	2.48	5.49	10.86	6.31
Total	99.93	100.02	100.02	99.9	100.09	99.71	99.6	99.79	99.77	99.83	99.73	99.71	99.73	99.61	99.43

The geochemistry results shows the SiO₂ which ranged from 46.61 wt. % to 70.76 wt. %, Al₂O₃ ranged from 4.13 wt. % to 12.86 wt. %, Fe₂O₃ ranged from 7.62 wt. % to 32.72 wt. % and MgO ranged from 0.50 wt.% to 0.622 wt. %.

Table 4.4: Geochemistry (XRF) results (wt. %) for Limpopo Province for April, July and September 2016

XRF	April 2016					July 2016					September 2016				
	Site A	Site B	Site C	Site D	Site E	Site A	Site B	Site C	Site D	Site E	Site A	Site B	Site C	Site D	Site E
SiO ₂	39.17	72.72	57.59	61.89	56.02	73.30	80.97	37.96	40.64	46.60	32.84	65.85	54.92	62.01	51.16
Al ₂ O ₃	11.41	12.53	18.08	6.55	19.17	7.21	5.29	3.84	6.13	5.75	2.58	11.12	18.32	9.48	20
Fe ₂ O ₃	16.38	2.95	9.03	11.24	11.88	6.35	5.07	50.70	44.71	34.98	3.45	4.63	8.18	10.49	12.69
MnO	0.145	0.045	0.103	0.295	0.109	1.87	0.143	0.294	0.387	0.337	0.165	0.066	0.091	0.229	0.089
MgO	9.59	1.78	0.42	7.62	0.62	0.81	0.65	0.94	0.56	1.12	30.07	3.74	0.49	5.7	0.68
CaO	1.57	1.85	0.12	0.91	0.18	1.64	1.18	0.59	0.38	1.53	0.43	2.22	0.26	0.41	0.09
Na ₂ O	0.01	3.2	<0.01	0.5	0.12	0.16	0.12	0.40	0.11	0.19	<0.01	2.36	0.08	0.15	0.08
K ₂ O	0.39	1.23	0.61	0.65	1.09	1.36	1.02	1.18	0.89	1.04	0.11	1.23	0.99	0.49	0.86
TiO ₂	0.74	0.3	0.9	0.8	1.95	0.64	1.23	0.21	0.54	0.75	0.11	0.36	0.82	0.53	2.01
P ₂ O ₅	0.344	0.086	0.115	0.158	0.141	0.146	0.136	0.124	0.178	0.238	0.193	0.229	0.185	0.095	0.16
Cr ₂ O ₃	0.256	0.045	0.085	0.892	0.037	0.035	0.038	0.029	0.035	0.033	0.271	0.092	0.059	0.439	0.03
LOI	19.57	2.8	12.64	8.09	8.16	6.33	3.90	3.30	4.93	7.21	30.07	8.14	15.53	10.14	11.98
Total	99.58	99.54	99.69	99.60	99.48	99.85	99.75	99.57	99.49	99.78	100.29	100.04	99.93	100.16	99.83

The oxides of the silicates minerals detected SiO₂ ranged from 32.84 wt. % at Site A , which is partially rehabilitated to 80.97 wt. % at Site B in September 2016 was fully rehabilitated. Al₂O₃ ranged from 2.58 wt. % at Site A to 20.00 wt. % at Site E which are partially rehabilitated. Fe₂O₃ ranged from Site A with 3.4 wt. % and Site E with 12.69 wt. %. The other oxides detected were of low values. According to a study by Moja *et al.* (2016), the dominance of SiO₂ ranged from 28.78 wt. % to 84.71 wt. % at all sites suggesting that all the sites contain silicate minerals. As compared to the results the oxides of the silicates minerals are within the same range. Other dominant oxides silicate include MgO (14.94 to 41.20 %) at sites A, B and C, Fe₂O₃ (10.65 to 38.45 wt. %) at sites A, D and E and Al₂O₃ (13.39 wt. %) at site B.

There is a relatively high loss on ignition (LOI); results range from 7.21 to 17.69 wt. % at sites A, B, C, D and E and were possibly due to H₂O presence in asbestos compounds, hydrocalcite and dolomite carbonate reported LOI levels of between 10.7 to 15.7 wt. % and accounted it to H₂ presence in chrysotile and carbonate minerals, such as the calcite dolomite and hydrocalcite.

Table 4.5: Geochemistry (XRF) results (wt. %) for Mpumalanga Province for January, April and July 2017

	January 2017					April 2017					July 2017				
XRF	Site A	Site B	Site C	Site D	Site E	Site A	Site B	Site C	Site D	Site E	Site A	Site B	Site C	Site D	Site E
SiO ₂	37.22	72.85	60.68	62.96	53.51	35.93	58.3	41.66	71.49	53.52	38.31	74.39	57.51	58.61	55.65
Al ₂ O ₃	6.83	12.82	17.79	8.13	18.93	4.92	18.49	3.51	14.87	18.26	2.73	12.26	15.92	8.51	18.31
Fe ₂ O ₃	5.53	3.38	8.57	9.42	12.74	7.02	6.4	10.36	2.32	12.67	4.11	2.61	7.58	10.19	11.45
MnO	0.286	0.042	0.055	0.274	0.15	0.215	0.091	0.226	0.034	0.152	0.214	0.035	0.115	0.344	0.099
MgO	32.64	0.7	0.46	6.64	0.73	27.42	2.28	24.07	0.37	0.78	38.22	1.35	0.49	6.81	0.68
CaO	1.06	1.89	0.06	1.34	0.17	0.79	3.27	1.13	0.66	0.16	0.17	1.86	0.34	0.75	0.25
Na ₂ O	<0.01	4.01	0.02	1.06	0.09	<0.01	3.43	0.17	3.67	0.04	<0.01	3.52	0.11	0.25	0.17
K ₂ O	0.06	1.32	0.82	1.07	1.13	0.23	1.59	0.42	3.97	1.11	0.02	1.27	1.11	0.60	0.91
TiO ₂	0.32	0.2	1.11	1.24	3.23	0.3	0.94	0.55	0.3	3.41	0.14	0.24	0.70	0.53	1.97
P ₂ O ₅	0.112	0.121	0.086	0.164	0.14	0.273	0.238	0.162	0.044	0.142	0.121	0.087	0.172	0.155	0.163
Cr ₂ O ₃	0.264	0.041	0.056	0.315	0.052	0.348	0.059	0.317	0.009	0.055	0.368	0.036	0.083	0.441	0.056
LOI	15.7	2.63	10.24	7.02	8.96	22.37	4.63	17.11	1.98	8.91	15.55	2.11	15.81	12.23	10.25
Total	100.02	100	99.95	99.63	99.83	99.82	99.72	99.69	99.72	99.21	99.95	99.77	99.94	99.42	99.96

In January 2017 the oxides of silicates minerals, which confirm the presence of asbestos minerals which was known to be a silicate mineral SiO₂, ranged from 37.22 wt. % at Site A to 72.85 wt. % at Site B which is fully rehabilitated and it confirms the presence of silicate minerals. Al₂O₃ ranged from 6.13 wt. % at Site A to 17.79 wt. % at Site C partially rehabilitated and Fe₂O₃ ranged from 3.38 for Site B to Site E with 12.74 wt. %. A comparable study found oxygen 46.6 wt. % and silicon 27.7 wt. % to be the main compounds of silicates minerals on the earth's crust.

Another similar bulk chemistry of mine waste samples in the US reported main compounds as SiO_2 (34.4 to 40.3 wt. %), MgO (35.2 to 38.8 % wt. %) and Fe_2O_3 (6.91 to 12.3 wt. % m/m) as well as lesser levels of Al_2O_3 (1.06 to 1.84 wt. %) (Lutgens and Tarbuck, 2000).

4.5.2 Asbestos load suspended in different substrate material

4.5.2.1 Asbestos load (% mineral) on the filtered dust sample by the XRD and SEM-EDS methods

Mineralogy results for Limpopo and Mpumalanga Provinces for April, July and September 2016 and January, April and July 2017 are presented. Quantitative mineralogical analysis has been conducted using an XRD PANalytical Empyrean diffractometer to identify and quantify the mineral composition that shows the presence of silicates and other general and non-silicate minerals.

The mineralogy results from Figure 4.12 to 4.15 shows the presence of significant levels of the serpentine and amphibole asbestos minerals, which was a major concern. Other dominant silicates minerals include quartz, mica, plagioclase, Illite, feldspar, goethite and non-silicate mineral calcite. Smectite and talc minerals exist almost in all the monitoring sites.

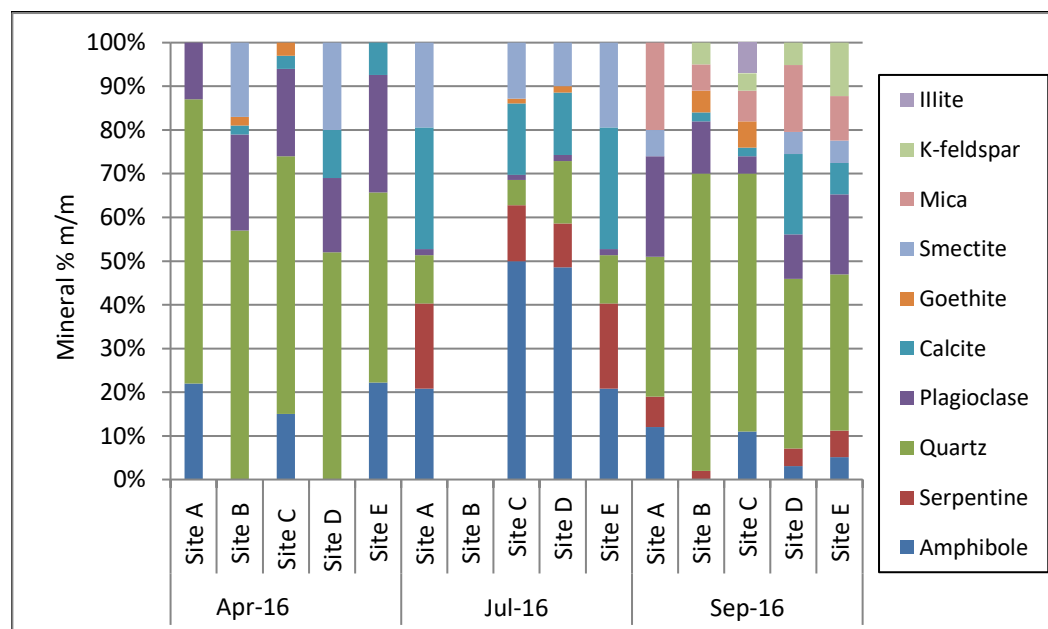


Figure 4.12: Mineralogy results for Limpopo Province in April, July and September 2016

The mineralogy result confirms the presence of amphibole and serpentine mineral group. The dominant mineral was quartz ranged from 5.0 % m/m to 68 % m/m, Serpentine from 2 % m/m to 14 % m/m, amphibole and plagioclase for all the sites. The lowest mineral detected were calcite non-silicate mineral ranged from 2.0 % m/m to 20 % m/m and goethite silicate mineral ranged from 1.0 % m/m to 6.0 % m/m. Site B in July 2016 was the highest with 68 % m/m, which is partially rehabilitated and Site A with 1.0 % m/m and Site C, D, E with 1.0 %m/m in April 2016.

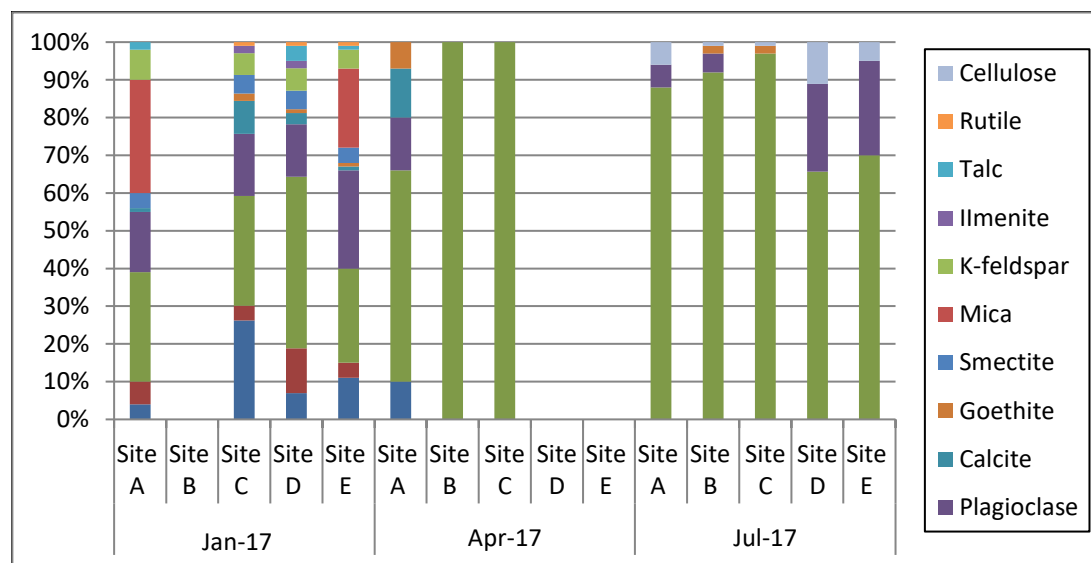


Figure 4.13: Mineralogy results for Limpopo Province for January, April and July 2017

The mineralogy results confirm the presence of amphibole ranged from 4.0 % mm to 27 % m/m and serpentine ranged from 4.0 % m/m to 12 % m/m mineral group. The dominant mineral detected quartz ranged from 25 % m/m at Site E to 46 % m/m at Site D and plagioclase ranged from 14 % m/m at Site D to 26 % m/m at Site E. The lowest mineral detected was calcite and goethite. Talc is known to indicate the presence of asbestos mineral and was also a silicate mineral. The health effect to quartz is silicosis and lung cancer whereas plagioclase was not classified as producing health effects. The economic benefits for quartz and plagioclase were manufacturing glass, ceramic, etc. Powder covered filters samples were analysed using x-ray diffraction. Despite the low amount of minerals present on most of the filters, the XRD analysis revealed the minerals present and how the respective weight percentages vary for each site during the month of July.

Minerals typically detected included plagioclase and quartz, with a strong presence of the cellulose filter for most filters for July 2017.

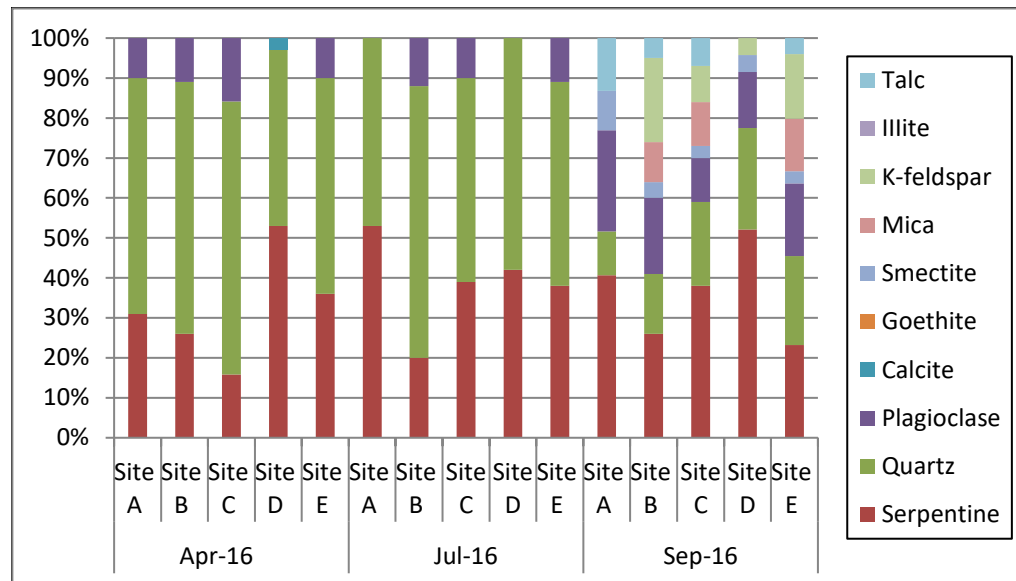


Figure 4.14: Mineralogy results for Mpumalanga province for April, July and September 2016

The mineralogy results confirm the presence of serpentine mineral ranged from 13 % m/m to 53 % m/m. The dominant minerals detected were quartz with 68 % m/m and plagioclase with 23 % m/m. The non-silicates minerals were calcite, goethite and smectite.

All the minerals found are classified as silicate except the calcite. Silicate minerals form the largest fraction (> 90 %) of most crustal rocks on earth (Marshall and Fairbridge, 2001). The chrysotile asbestos which is part of the serpentine group is known to have been mined and milled in Mpumalanga (Moja *et al.*, 2016). The amphibole asbestos group was not mined in Mpumalanga Province and it could have been unintentionally exposed or released as an accessory trace mineral when core minerals such as gold were mined (Visser and Ehler, 1998).

The economic benefits of quartz, plagioclase and k-feldspar include being used to manufacture glass ceramics and ceramics, while mica manufacture plates, radar circuit, and discs. Serpentine are used to manufacture brake pads for vehicles and amphibole is used to manufacture ceilings (Clayton, 1981; Jee, 2003).

Adverse health effects associated with occupational exposure to chrysotile or serpentine asbestos mineral group include illnesses such as fibrosis (asbestosis), lung cancer and mesothelioma (WHO, 1998). The recommended airborne exposure limit is 3 mg/m³ for chrysotile averaged over a 10-hour workshift (NIOSH, 1978). Dust containing mica may cause pneumoconiosis (Zinman *et al.*, 2002), which is an occupational lung disease and a restrictive lung disease caused by the inhalation of dust containing mica, often in mines. Exposures to relatively low concentrations of quartz may be capable of causing hilar node fibrosis (Seaton *et al.*, 1998). This is characterized by localization of the fibrosing process to one or both pulmonary hila. This results in pulmonary hypertension and bronchial narrowing (Magdi *et al.*, 1971). Occupational quartz dust exposure may also cause silicosis. Silicosis, a nodular pulmonary fibrosis or fibrotic lung disease, is caused by the inhalation and deposition of respirable crystalline silica particles (i.e., particles <10 µm in diameter) (Ziskind, 1976; Cox-Ganser, 2009).

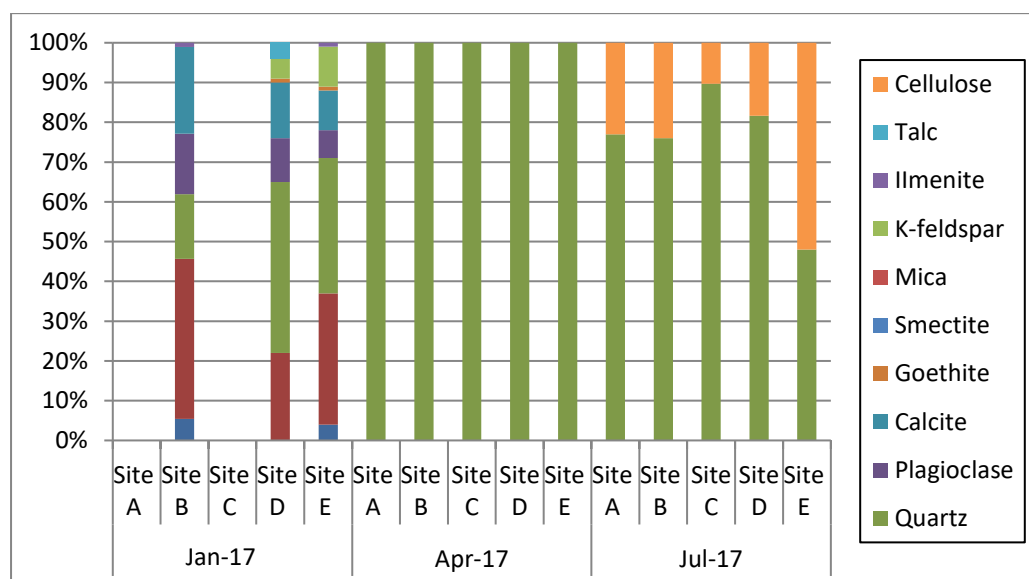


Figure 4.15: Mineralogy results for Mpumalanga Province for January, April and July 2017

The mineralogy results for September 2016 for Mpumalanga Provinces confirm the presence of amphibole ranging from 4 % m/m to 4 % m/m and serpentine ranging 22 % m/m to 37 % m/m. The dominant silicates minerals detected were quartz and plagioclase and non-silicate minerals detected were calcite, goethite and smectite. The other silicate minerals were ilmenite, k-feldspar, rutile, mica and talc.

4.3.5 SEM-EDS results from filtered dust and trapped dust samples

Table 4.6 shows percentage mineral count measured mainly in Limpopo province. All the sites in Limpopo Province show the presence of amphibole asbestos mineral which ranged from 8.0 % in Site C to 56 % in Site D. The serpentine asbestos mineral was only detected in two different months with 1.0 and 2.0 % at Site A, well as at three sites in Mpumalanga Province with 7.0 % at Site D, 3.0 % at Site A and 2.0 % at Site B. Other dominant silicate minerals include the quartz, feldspar, mica, kaolinite and plagioclase. A significant presence of organic matter and iron oxides was also detected in the exposed filter substrates.

Table 4.6: SEM-EDS and percentage mineral count for filtered dust samples for Limpopo and Mpumalanga Provinces

Sampling Points	% mineral count								
Limpopo Province: April 2016	Amphibole	Serpentine	Feldspar	Quartz	Plagioclase	Kaolinite	Mica	Organic	Iron oxide
Site A	26	2	30	ND	ND	ND	2	5	2
Site B	39	ND	18	ND	ND	ND	ND	8	4
Site C	21	ND	31	ND	3	ND	ND	3	15
Site D	56	ND	8	ND	ND	ND	ND	3	6
Site E	42	ND	27	ND	3	ND	ND	3	ND
Limpopo Province: July 2016									
Site A	38	ND	7	19	ND	4	1	11	4
Site B	37	ND	2	37	ND	2	ND	2	13
Site C	26	ND	6	28	ND	ND	ND	2	13

Site D	24	ND	2	27	ND	2	2	13	2
Site E	42	ND	5	22	ND	2	ND	8	5
Mpumalanga Province: April 2016									
Site A	23	3	4	32	ND	4	2	13	3
Site B	5	2	9	33	ND	3	5	5	3
Site C	15	ND	8	30	ND	3	ND	15	8
Site D	36	7	6	15	ND	ND	1	3	12
Site E	12	ND	12	24	ND	10	ND	2	5
Limpopo Province: September 2016									
Site A-Site E	ND	ND	ND	ND	ND	ND	ND	ND	
Mpumalanga Province : April 2017									
Site A to Site E	ND	ND	ND	ND	ND	ND	ND	ND	
Limpopo Province: January 2017									
Site A to Site E	ND	ND	ND	ND	ND	ND	ND	ND	
Mpumalanga Province: January 2017									
Site A	5	ND	ND	ND	ND	26	ND	ND	
Site B	17	ND	ND	ND	4	17	ND	ND	
Site C	ND	ND	7	ND	ND	29	ND	4	
Site D	8	ND	8	4	ND	ND	ND	ND	
Site E	22	ND	ND	ND	ND	ND	ND	ND	
Limpopo Province : April 2017									
Site A to Site E	ND	ND	ND	ND	ND	ND	ND	ND	
Mpumalanga Province: April 2017									

Site A to Site E	ND	ND	ND	ND	ND	ND	ND	ND	
Limpopo Province: July 2017									
Site A to Site E	ND	ND	ND	ND	ND	ND	ND	ND	

ND: Not detected

Some low levels of asbestos minerals types were detected in provinces where they were originally not mined. This presence can be explained because asbestos mineral was part of the dominant silicate minerals on the surface of the earth. Secondly, low levels of asbestos minerals can unintentionally be extracted when main targeted minerals are being mined.

From Figure 4.16 to Figure 4.19 SEM-EDS results were shown of filtered dust and trapped dust samples for Limpopo and Mpumalanga Provinces. Appendix B shows all SEM-EDS image results from filtered dust and trapped dust samples.

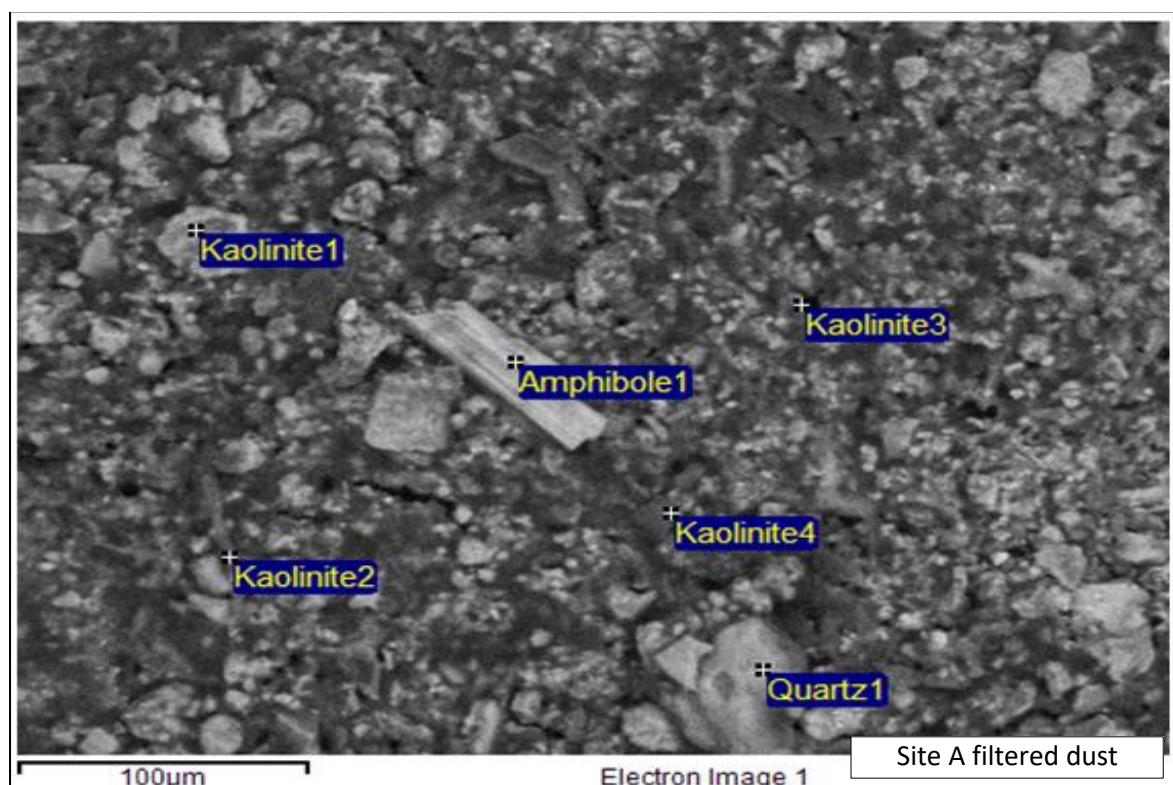


Figure 4.16: SEM-EDS results for Mpumalanga Province for July 2016

Results of Figure 4.16 confirm the presence of amphibole $[\text{NaCa}_2(\text{Mg,Fe,Al})_5(\text{Al,Si})_8\text{O}_{22}(\text{OH})_2]$ mineral group and kaolinite $[\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4]$. At all the sites the size particles was 100 μm – 500 μm for semi-rectangular, semi-triangular and the shape characterized by straw or bundle clustered together.

In a similar study undertaken around residential areas in Vermont and Washington in the US, soil samples were found to be contaminated with the amphibole asbestos minerals and other minerals (Thompson et al., 2011). Another related study has demonstrated that the transmission electron microscopy (TEM) and conventional phase contrast microscopy (PCM) were effective in determining asbestos fibres from the surface dust samples, which were > 5 μm length (Folwer and Chatfield, 1997; USEPA, 1987).

Figure 4.17 shows minerals detected by SEM-EDS amphibole, quartz and kaolinite.

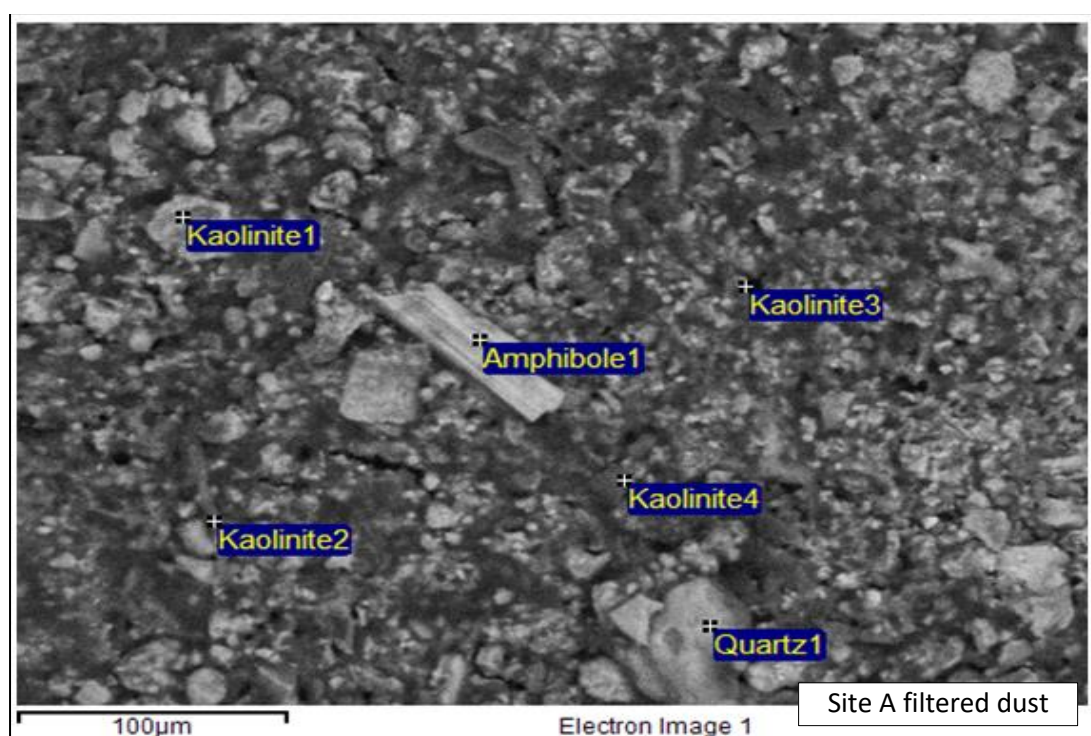


Figure 4.17: SEM-EDS results for July 2016 for Limpopo Province

Figure 4.18 shows the results which confirm the presence of amphibole $[\text{NaCa}_2(\text{Mg,Fe,Al})_5(\text{Al,Si})_8\text{O}_{22}(\text{OH})_2]$ mineral group and other silicate minerals were talc. The non-silicate mineral detected was silver, halite and copper. At all the sites the size particles is 50 μm was for granular and sponge-like shape.

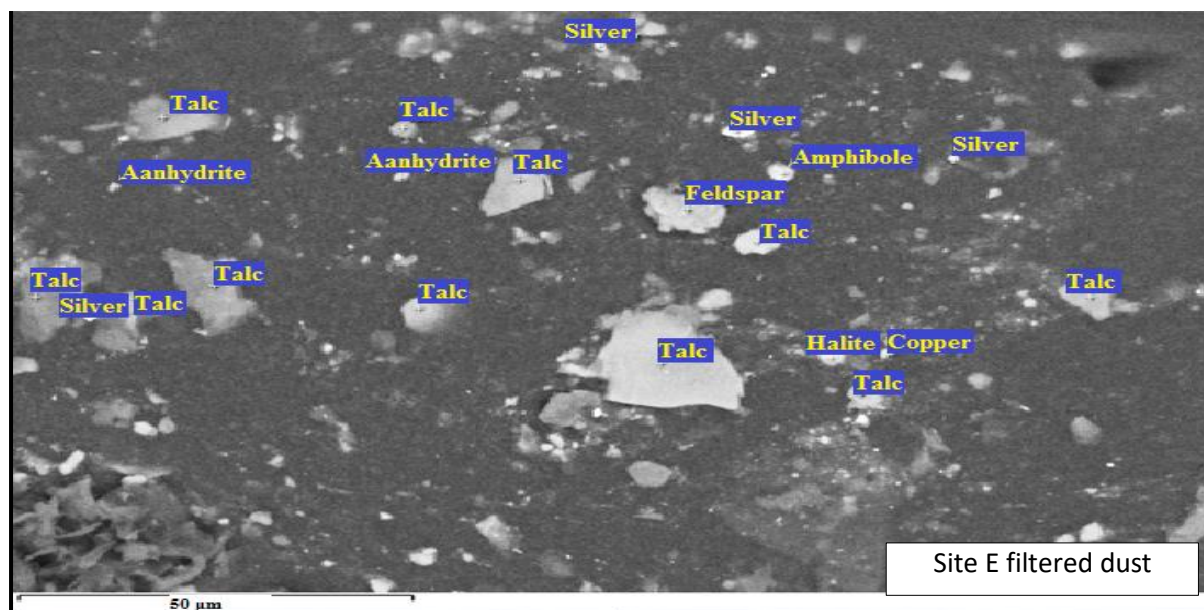


Figure 4.18: SEM-EDS results for Limpopo Province January 2017

Figure 4.19 shows amphibole, serpentine, quartz and feldspar and non-silicate mineral detected Fe-oxide.

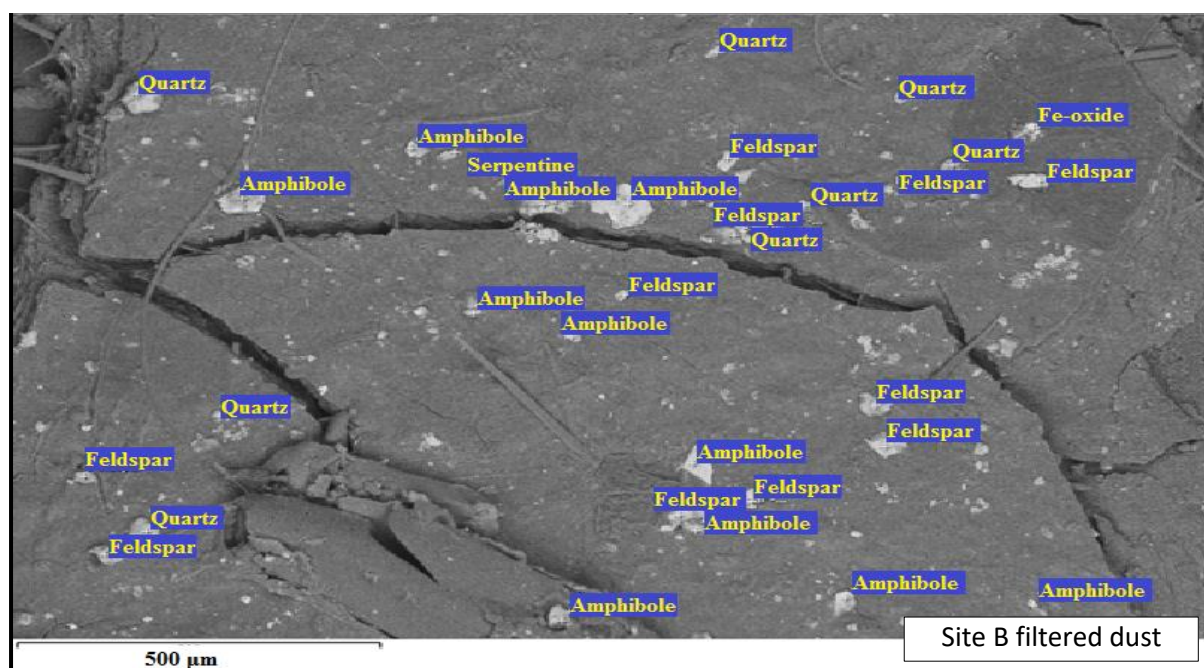


Figure 4.19: SEM-EDS results for January 2017 for Mpumalanga Province

4.5.4 Asbestos load (% mineral) on the trapped dust samples by SEM-EDS methods

Table 4.7: SEM-EDS and Percentage mineral count for trapped dust samples for Limpopo and Mpumalanga Provinces

Sampling points	% mineral count														
	Amphiboles	All feldspar	Quartz	Calcite	Fe-oxide	Mica	Organic	Gypsum	Kaolinite	Talc	Zincite	Dolomite	Halite	Ilmenite	Calcium silicate
Limpopo Province/ April 2016															
Site A trapped dust	40	27	13	7.0	4.0	4.0	2.0	ND	ND	ND	ND	ND	ND	2.0	ND
Site B trapped dust	29	29	12	6.0	6.0	ND	6.0	ND	6.0	ND	6.0	ND	ND	ND	ND
Site C trapped dust	43	14	14	ND	ND	ND	14	ND	ND	ND	ND	ND	ND	ND	ND
Site D trapped dust	3 3	10	ND	33	ND	ND	ND	5.0	ND	19	ND	ND	ND	ND	ND
Site E unit trapped dust	41	16	19	4.0	4.0	9.0	2.0	1.0	1.0	ND	ND	1.0	1.0	1.0	ND
Limpopo Province- January 2017															
Site A trapped dust	40	27	13	7.0	4.0	4.0	2.0	ND	ND	ND	ND	ND	ND	2.0	ND
Site B trapped dust	29	29	12	6.0	6.0	ND	6.0	ND	6.0	ND	6.0	ND	ND	ND	ND
Site C trapped dust	43	14	14	ND	ND	ND	14	ND	ND	ND	ND	ND	ND	ND	ND
Site D trapped dust	33	10	ND	33	ND	ND	ND	5.0	ND	19	ND	ND	ND	ND	ND
Site E trapped dust	70	9.0	9.0	4.0	4.0	ND	ND	ND	4.0	ND	ND	ND	ND	ND	ND
Mpumalanga Province January 2017															
Site A trapped dust	13	ND	ND	3.0	ND	ND	7.0	ND	ND	20	7.0	ND	ND	ND	ND
Site B trapped dust	5.0	ND	15	ND	5.0	5.0	ND	ND	ND	ND	5.0	10	ND	ND	ND
Site C trapped dust	8.0	ND	ND	8.0	ND	ND	ND	ND	4.0	ND	ND	ND	25	ND	ND

Site D trapped dust	25	ND	2.0	ND	ND	ND	9.0	ND	5.0	ND	ND	2.0	2.0	ND	2.0
Site E trapped dust	5.0	ND	ND	25	10	ND	ND	ND	ND	5.0	ND	5.0	ND	ND	ND
Mpumalanga Province July 2017															
Site A trapped dust	28	10	10	3.0	3.0	ND	ND	ND	8.0	ND	ND	ND	ND	ND	ND
Site B trapped dust	27	27	12		4.0	ND	ND	6.0	10	2.0	ND	ND	ND	ND	ND
Site C trapped dust	21	21	16	ND	ND	16	ND	ND	11	ND	ND	ND	ND	ND	ND
Site D-E trapped dust	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND: Not detected

Table 4.7 shows the percentage asbestos mineral counted per total miner count amphibole and serpentine asbestos minerals. Other silicate minerals detected are quartz, kaolinite, talc, feldspar, calcium silicate and non-silicate minerals calcite, phosphate, organic, gypsum, ilmenite, halite, gibbsite and fe -oxide.

Figure 4.20 to Figure 4.22 shows mineral detected on trapped dust samples which shows that amphibole asbestos mineral groups were detected in all the sites. All the feldspar and quartz are the most dominate silicate minerals. The non-silicate minerals detected were calcite, gypsum and organic.

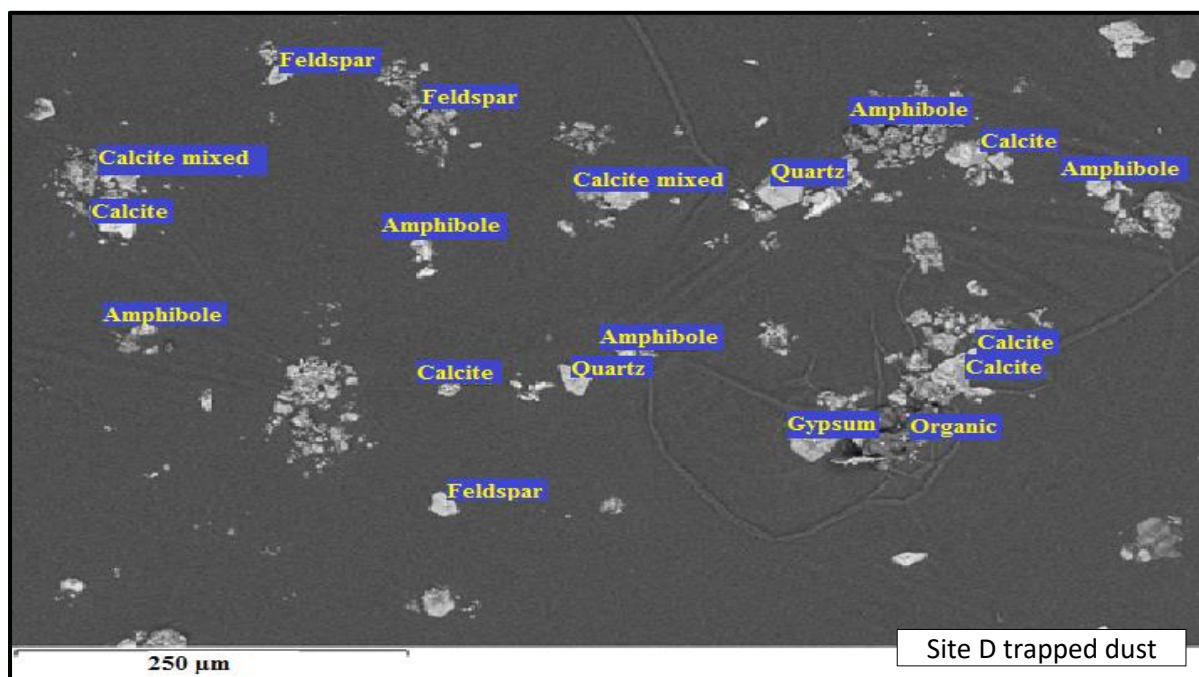


Figure 4.20: SEM-EDS results for January 2017 for Limpopo Province

Figure 4.20 shows that the dominant minerals were amphibole and serpentine. Quartz and other silicate minerals detected were mica. The non-silicate minerals detected were calcite, Zn oxide, organic, gypsum, Al-Si-Zn oxide and kaolinite.

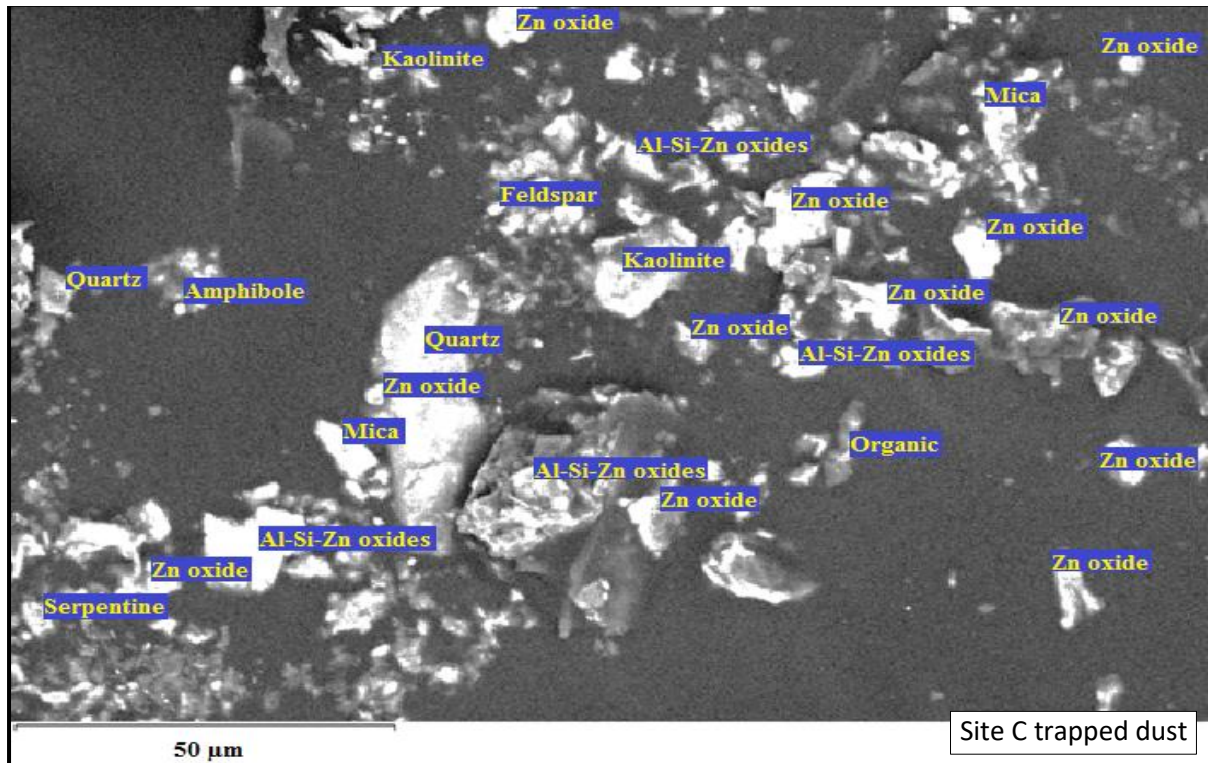


Figure 4.21: SEM-EDS results for January 2017 for Mpumalanga Province

Figure 4.22 shows that amphibole, quartz, feldspar and other oxides were the dominance mineral detected. All the two sites partially rehaibilitated and three sites unrehabilitated sites. The non-silicate minerals Al-Fe-Si-O, Cr-Fe, Ca-Fe-O and Fe-Ti-O (See Appendix B).

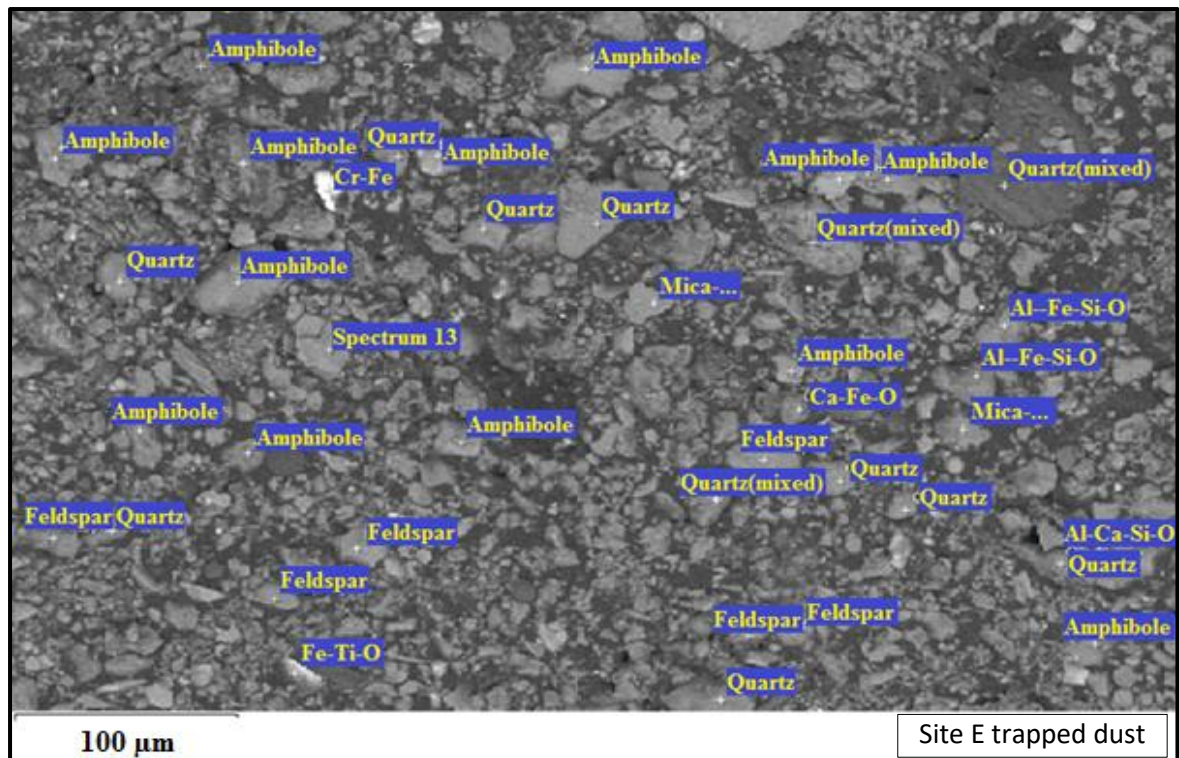


Figure 4.22: SEM-EDS results from July 2017 for Limpopo Province

Figure 4.23 shows that mineral detected are amphibole, quartz, mica and talc which was an indication that the sample of interest has asbestos mineral. The non-silicate minerals detected were calcite, feldspar, Al-Ca-Si-O, Al-Fe-Si-Ti-O, Al-Ca-Mg-Si-O, Cr-Fe and organic.

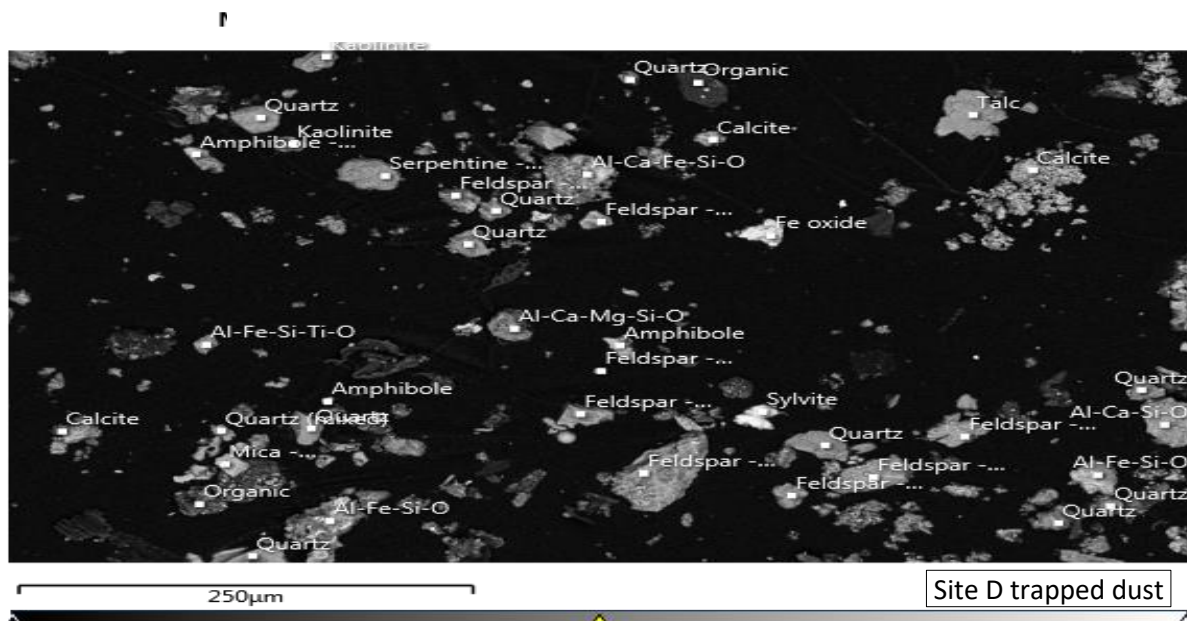


Figure 4.23: SEM-EDS results for July 2017 for Mpumalanga Province

4.5.5 Adaption of mineral count method for asbestos load (fibre count) on the AirCon 2 sampler filter

4.5.5.1 Asbestos load (fibre count) on the E-sampler filter by the PCM method

Table 4.8 shows the asbestos fibre counting results from E-sampler from January to December 2017. Note that insufficient sample (IS) in the table means that the airborne dust samples captured on the filter substrates were very little and no asbestos fibres could be detected. Of a total of 120 of exposed filter papers used in the official asbestos fibre Air Con 2 sampler, 30 filters had positive presence of asbestos fibres, making it 23% collection efficiency (see content in Tables 4.10 and 4.11). Of the 100 exposed filter papers used in for E-samplers, 9% collection efficiency was recorded (see content in Tables 4.8 and 4.9).

Table 4.8: Limpopo Province (f/mL) asbestos fibres count results from E-sampler from January to December 2017

Dates	C/No. of Fibres	Site A	Site B	Site C	Site D	Site E
17-Jan	No. of Fibers/200 fields	IS	IS	IS	2	IS
	Conc. (f/mL)				0,00022	
17-Feb	No. of Fibers/200 fields	IS	2	IS	IS	IS
	Conc. (f/mL)		0,00022			
17-Mar	No. of Fibers/200 fields	IS	IS	IS	IS	IS
	Conc. (f/mL)					
17-Apr	No. of Fibers/200 fields	IS	IS	IS	IS	IS
	Conc. (f/mL)					
17- May	No. of Fibers/200 fields	IS	IS	IS	IS	IS
	Conc. (f/mL)					
17-Jun	No. of Fibers/200 fields	IS	IS	IS	IS	IS
	Conc. (f/mL)					
17-Jul	No. of Fibers/200 fields	1	IS	IS	4.5	IS
	Conc. (f/mL)	0,00011			0,00049	
17-Oct	No. of Fibers/200 fields	1	IS	IS	1	IS
	Conc. (f/mL)	0,00011			0,00011	
17-Nov	No. of Fibers/ 200 fields	2	IS	IS	4	IS
	Conc. (f/mL)	0,00022			0,00043	
17-Dec	No. of Fibers/200 fields	IS	IS	IS	IS	IS
	Conc. (f/mL)					

IS: Insufficient sample

Table 4.9: Mpumalanga Province (f/mL) asbestos fibre count results from E-sampler from January to December 2017

Dates	C/No. of Fibres	Site A	Site B	Site C	Site D	Site E
17-Jan	No. of Fibers/200 fields	IS	IS	IS	IS	IS
	Conc. (f/mL)					
17-Feb	No. of Fibers/200 fields	IS	IS	IS	IS	IS
	Conc. (f/mL)					
17-Mar	No. of Fibers/200 fields	IS	IS	IS	IS	IS
	Conc. (f/mL)					
17-Apr	No. of Fibers/200 fields	IS	IS	IS	IS	IS
	Conc. (f/mL)					
17-May	No. of Fibers/200 fields	IS	IS	IS	IS	IS
	Conc. (f/mL)					
17-Jun	No. of Fibers/200 fields	IS	IS	IS	IS	IS
	Conc. (f/mL)					
17-Jul	No. of Fibers/200 fields	IS	IS	IS	IS	IS
	Conc. (f/mL)					
17-Oct	No. of Fibers/200 fields	IS	IS	IS	IS	IS
	Conc. (f/mL)					
17-Nov	No. of Fibers/200 fields	IS	IS	IS	IS	IS
	Conc. (f/mL)					
17-Dec	No. of Fibers/200 fields	IS	IS	IS	IS	IS
	Conc. (f/mL)					

IS: Insufficient sample

4.5.2 Asbestos load (fibre count) on the Air Con 2-filter by the PCM method

All airborne asbestos fibres which were captured on the filter substrates per 200 fields with length $> 5.0 \mu\text{m}$ and $< 3.0 \mu\text{m}$ diameter were below the limit value of 100 f/mL for asbestos fibre suspension in air (MDHS 39/4,1995), Occupational safety and health administration (OSHA, 2012) limit 0, 1 f/mL 2000 (Tables 4.10 and 4.11).

The highest airborne asbestos fibres and concentration count measured was 40 fibres and 0,00434 f/mL concentration in October at Site A. The second highest fibre and concentration counts were measured in September with 26,5 fibres and 0,00287 f/mL concentrations at Site B, as well as 11,5 fibres and 0.00125 f/mL concentration at Site D in June. The third highest fibre and concentration counts were measured in June 2017 10 fibres and 0,01085 f/mL concentrations in Site A. Some of the exposed filters did not have enough samples and are presented as insufficient samples in the above and below mentioned tables. All the sites shows the variable presence of asbestos fibres which is not unexpected because the sites are very close to the asbestos mined areas.

Table 4.10: Limpopo Province (f/mL) asbestos fibre count for AirCon and filter from January to December 2017

Dates	C/No. of Fibers	Site A	Site B	Site C	Site D	Site E
17-Jan	No. of Fibers/200 fields	1	IS	IS	IS	1
	Conc. (f/mL)	0,00011				0,00011
17-Feb	No. of Fibers/200 fields	IS	IS	2	IS	IS
	Conc. (f/mL)			0,00022		0
17- Mar	No. of Fibers/200 fields	IS	IS	IS	IS	IS
	Conc. (f/mL)					
17-Apr	No. of Fibers/200 fields	IS	IS	IS	IS	1
	Conc. (f/mL)					0,00011
17- May	No. of Fibers/ 200 fields	IS	IS	IS	IS	IS
	Conc. (f/mL)					
17-Jun	No. of Fibers/200 fields	11.5	3.5	IS	10	3
	Conc. (f/mL)	0,00125	0,00027		0,01085	0,00033
17-Jul	No. of Fibers/200 fields	1	2.5	IS	IS	3
	Conc. (f/mL)	0,00011	1,318	0	0	1,582

	No. of Fibers/200 fields	1	IS	1	IS	IS
17- Aug	Conc. (f/mL)	0,00011	0,00282	0,00011		
	No. of Fibers/200 fields	IS	26,5	IS	IS	IS
17-Sept	Conc. (f/mL)		0,00287			
	No. of Fibers/200 fields	40	4	IS	2	6
17-Oct	Conc. (f/mL)	0,00434	0,00043		0,00022	0,00065
	No. of Fibers/200 fields	3.5	IS	IS	IS	3
17-Nov	Conc. (f/mL)	0,00038				0,00033
	No. of Fibers/200 fields	IS	2.5	1	SD	SD
17-Dec	Conc. (f/mL)		0,00027	0,00011		

IS: Insufficient sample

Table 4.11: Mpumalanga Province (f/mL) asbestos fibre count for AirCon and filter from January to December 2017

Dates	C/No. of Fibers	Site A	Site B	Site C	Site D	Site E
	No. of Fibers/200 fields	IS	IS	IS	IS	IS
17-Jan	Conc. (f/mL)					
	No. of Fibers/200 fields	IS	IS	IS	IS	IS
17-Feb	Conc. (f/mL)					
	No. of Fibers/200 fields	IS	1	1	IS	IS
17- Mar	Conc. (f/mL)		0,00011	0,00011		
	No. of Fibers/200 fields	IS	IS	IS	6	IS
17- Apr	Conc. (f/mL)				0,00065	
	No. of Fibers/200 fields	IS	IS	IS	IS	IS
17-May	Conc. (f/mL)					
	No. of Fibers/ 200 fields	IS	IS	IS	IS	IS
17- Jun	Conc. (f/mL)					
	No. of Fibers/200 fields	1			4,5	
17-Jul	Conc. (f/mL)	0,00011	IS	IS	0,00049	IS
	No. of Fibers/200 field	IS	IS	IS	1	IS
17-Aug	Conc. (f/m)				0,00011	
	No. of Fibers /200 fields	3,5	IS	IS	IS	0,5
17- Sept	Conc. (f/mL)	0,00038				0,00005
17-Oct	No. of Fibers/200 fields	IS	IS	IS	IS	IS

	Conc. (f/mL)					
17-Nov	No. of Fibers/200 fields	IS	IS	IS	IS	IS
	Conc. (f/mL)					
17-Dec	No. of Fibers/200 fields	IS	IS	IS	IS	IS
	Conc. (f/mL)					

IS: Insufficient sample.

Therefore, the official asbestos fibre Air Con 2 sampler has 15 % more collection efficiency than the general particulate matter E-sampler. These results could also mean that a general particulate matter high volume sampler can still be used for asbestos fibre monitoring in the absence of a specific and selective Air Con 2 sampler, as long as the user appreciates about 15 % collection deficiency.

4.6 The novelty and summary of the study

In comparing the performance of the officially recognized and approved (ASTM D1739:1970) method against the unofficial, but commonly used (ASTM D1739:1998) method, this study found the unofficial method to be performing better in settleable dust sample collection and sample management. The researcher found no clear reason in the literature why the best performing method (ASTM D1739:1998) was not recommended by the Department of Environmental Affairs. However, this study concludes that it could be due to the different windshield designs that makes it difficult to compare or regulate the ASTM D1739:1998 method (see figure 2.6 on page 51 in Chapter 2). Both methods show the presence of water to be playing a significant role with more settleable dust being retained in units that contained water than when water was absent. The results also show that the water spiked with an algaecide was easier to filter and gave rise to higher dust retention yields (Figure 4.1). Also, the results show that 5 % CuSO_4 yielded higher mass concentration of settleable dust than 5 % NaOCl . A different study in the literature did not approve of 5.0 % sodium hypochlorite (NaOCl) algaecide solution due to its crust forming abilities (Loans, 2007).

The second part of the method for testing was undertaken in the laboratory on asbestos contaminated settleable filters.

After several attempts, trials and/or errors in the laboratory, the adapted method was successfully used to identify and quantify asbestos and other minerals that are present in a prepared filtered settleable dust sample using the mineralogy count approach.

The potential future application of the method was confirmed when an official acceptable asbestos fibre count method found similar types of minerals to be present within the same sites, as well as comparable quantities of asbestos minerals (see section 4.5.2).

Also, the method validation gave additional new information. Of a total of 120 of exposed filter papers used in the official asbestos fibre Air Con 2 sampler, 28 filters had positive presence of asbestos fibres, making it 23 % collection. And of the 100 exposed filter papers used in for E-samplers, only 8 % collection efficiency was recorded. The results means that the official asbestos fibre Air Con 2 sampler has 15% more collection efficiency than the general particulate matter E-sampler for airborne asbestos monitoring. The impact of these results could also be that a general particulate matter high volume sampler can still be used for asbestos fibre monitoring in the absence of a specific and selective Air Con 2 sampler, as long as the user appreciates about 15 % collection deficiency.

The predication of the falling settleable dust from the mine dumps shows at settleable dust fall easily at 1 μm and 5 μm particle dust diameter between 37.667 and 48.04 hours settleable dust to fall on the ground, but at the 10 μm it takes 0.6255 and 0.6276 hours for settleable dust to fall on the ground. These prediction are both for Limpopo and Mpumalanga Provinces.

The geochemistry results confirm the presence of oxides of silicates minerals SiO_2 , Al_2O_3 , Fe_2O_3 and MnO and were of high values. These results are the first set of analytical data that confirm the presence of silicate minerals in the samples, one which is asbestos mineral. The other oxides detected of lowest values were MgO , CaO , Na_2O , K_2O , TiO_2 , P_2O_5 and Cr_2O_3 .

The percentage mineral count results shows significant presence of asbestos minerals with 23 % amphibole asbestos mineral that at Site C and 33 % of the amphibole asbestos mineral at Site E in Limpopo Province. Talc is known as asbestos indicator mineral and was found in significant less of 52 % at Site B (source/s).

A noticeable presence of about 26 % of serpentine asbestos minerals was found at Site A in Mpumalanga Province.

The noticeable presence of both amphibole and serpentine asbestos minerals in airborne dust samples in the study areas increases the potential to be inhaled due to the close proximity of human settlements to the asbestos dump sources. Inhaled asbestos mineral dust has been reported to cause human health challenges like lung diseases.

The mineralogy and SEM - EDS results on the filtered dust and sticky tape samples results also confirm the presence of amphibole and serpentine asbestos mineral in the study areas. The dominant silicate mineral detected are quartz, mica and plagioclase as the dominant silicate minerals. The quartz mineral known to cause health effects such as silicosis (Clayton, 1981-1982). The economic benefits for quartz and plagioclase was their use in the manufacture of glass ceramics and other products, etc. (Clayton, 1981-1982).

The average dust particle sizes ranged from 2.0 μm to 250 μm and were mainly semi-rectangular, semi-triangular in shapes. Most particles were in straw form or were bundles clustered together in shape. Curved, spiral and granular in shapes. The smaller particle sizes like 2.0 μm contributes to serious health impacts to their ability to penetrated the body defenses in the nose and be deposited deep in the lungs (Amatullah *et al.*, 2012).

The brownish colour of the exposed filters from Limpopo Province was similar to amosites asbestos mineral of the amphibole mineral group that was mined in Limpopo Province. The exposed filters from Mpumalanga Province were whitish or greyish in colour, which is similar to the asbestos chrysotile mineral mined from the local sites.

The results confirm the influence of the local geology in the composition of the mineralogy, which include the Transvaal Supergroup, Chuniespoort group whereas in Mpumalanga Province which are known sources of both amphibole and chrysotile minerals (Visser, 1998).

Asbestos fibre counts from AirCon 2 sampler and E-sampler are below 0.001 f/mL according to the Occupational Health and Safety Act No. 39 of 1993 and 100 f/mL MDHS 34/4, 1995 all the fibres counted were below the limits in June, September and October 2017 for Limpopo Province which are the highest in terms of fibre counting and concentrations. All the asbestos fibres and concentration for the AirCon 2 sampler and E-sampler are below the limit of OHSA no.39 of 1993 and MDHS 39/4 1995 for Mpumalanga Province.

The study succeeded in determining the presence of asbestos minerals in the study areas, as well as quantifying the amount of asbestos minerals on the exposed filters using the adapted mineral count method. The outcome of the method, including the asbestos mineral method contamination of the sites was also successfully validated through the application of the official and non-official asbestos fibre count method.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter presents the conclusion of the findings of the research, including identifying possible correlations between different parameters and analyses used to quantify asbestos fibres and mineral count that were captured in different filter substrates.

5.2 Conclusion

The pilot study was conducted to compare the performance of ASTM D1739:1998 and ASTM D1739:1970 methods of collection and analysis of settleable dust samples. In both methods, the presence of water alone and water with algaecide gave rise to higher settleable dust rates. Also, the ASTM D1739:1998 methods gave rise to higher retention of settleable dust in the monitoring units. Unfortunately, this best performing method, ASTM D1739:1998, is not legislated or regulated by the government.

This researcher concludes that the reasons could be due to the different shapes of the windshield designs that may make it difficult to standardize and control. However, this information gap provides an opportunity of a longer focused study of this method with the intention of finding a standardized windshield design that could be recommended for use in the country.

After the pilot study, this investigation continued to use the officially recognized method, ASTM D1739:1970 (NDCR no.827, 2013) in the search for a cost effective method to determine the presence of asbestos hazard in environmental samples. The study established that the adapted asbestos mineral count method succeeded to identify and quantify the asbestos minerals that existed in the settleable dust samples collected from the study areas. The outcome of this method was successfully validated with the test undertaken using the officially recognized method of asbestos fibre count method (MDHS 39/4, 1995).

Both approaches found the asbestos hazard to be present in settleable dust and airborne collected dust samples and that has a serious implication to the health condition of the exposed nearby human population. The adapted mineral count method provides the research community with an alternative, cost effective and user-friendly method of analysis. The method allows easy access to the wider participation in the air quality research, which is known to be exclusive due to the high cost of active monitoring techniques. Currently, most researchers from the historically disadvantaged universities have no access to air quality monitoring techniques that include the E-sampler and the AirCon 2, which limit their involvement or participation and makes this research domain exclusive. It is also difficult to share such monitoring equipment's because they are few and their use requires long campaigns at specified sites to generate useful data.

5.3 Recommendations

Since this study has determined that the ASTM D1739:1998 method performed better than the officially recognized method, the researcher recommends that this method be considered by the regulators of air quality in the country. But, the method will first require some improvement and standardization especially on the wind shield designs before it could be officially accepted as the method of collection and analyses of settleable dust. It was hoped that the air quality research community will take up the challenge.

Overall, a permanent solution to the derelict and ownerless asbestos mine dump problems is rehabilitation, restricting access and relocation of communities away from such point sources.

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APPENDIX

APPENDIX A: Meteorological data

Table 1: Average monthly parameters recorded at Mokopane station in Limpopo Province (SAWS, 2016, 2017)

Season	Period	Temperature (°C)		Humidity (%)	Rainfall (mm)	Wind speed (m/s ⁻¹)
		Maximum	Minimum			
Autumn	Apr-16	30	13.8	66.8	6.6	0.8
	May-16	24.9	8.8	69.3	5	0.7
Winter	Jun-16	23.6	5.8	69.7	4	0.5
	Jul1-6	23.4	5	60.8	1.4	0.9
	Augu-16	27.9	7.6	50.7	0	0.8
Spring	Sept-16	30.1	14.5	53.8	0	1.8
	Oct-16	32	16.4	52.7	24.2	1.9
	Nov-16	31.4	17.2	63.9	72.6	1.9
Summer	Dec-16	31.8	18.5	68.6	61	1.3
	Jan-17	30.7	18.5	71.1	48	1.3
	Feb-17	30.8	18.7	74.1	34.8	1.2
Autumn	Mar-17	32.0	17.6	73.3	17.0	0.9

Table 2: Average meteorology parameters for Nelspruit for Mpumalanga Province
(SAWS, 2016, 2017)

Season	Period	Temperature (°C)		Humidity (%)	Rainfall (mm)	Wind speed (m/s)
		Maximum	Minimum			
Autumn	Apr-16	27.2	15.4	69.4	19.8	0.6
	May-16	22.7	11.6	72.6	18	0.8
Winter	Jun-16	22.9	10.3	63.3	3.4	1.3
	Jul-16	21.7	8.7	60.7	21.2	1.3
	Aug-16	24.9	9.2	54.5	6	0.7
Spring	Sept-16	26.5	13.9	58.5	1.8	1
	Nov-16	25.6	17.3	74.6	32.2	1.4
	Oct-16	26.2	15.1	66.3	1.8	1.3
Summer	Dec-16	27.8	18.3	70.5	136.6	1
	Jan-17	26.8	18.3	75.8	198.6	1.2
	Feb-17	26.6	18.8	79.1	144.2	1.1
	Mar-17	28.5	19.1	77.7	152.2	2.5

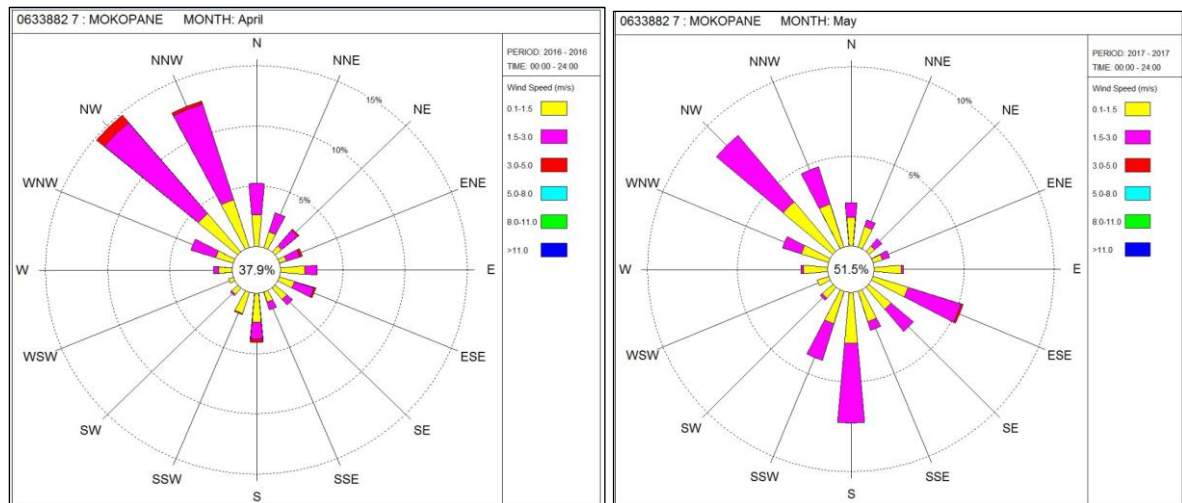


Figure 1: Monthly average wind rose for Mokopane for April and May 2016 (autumn season)

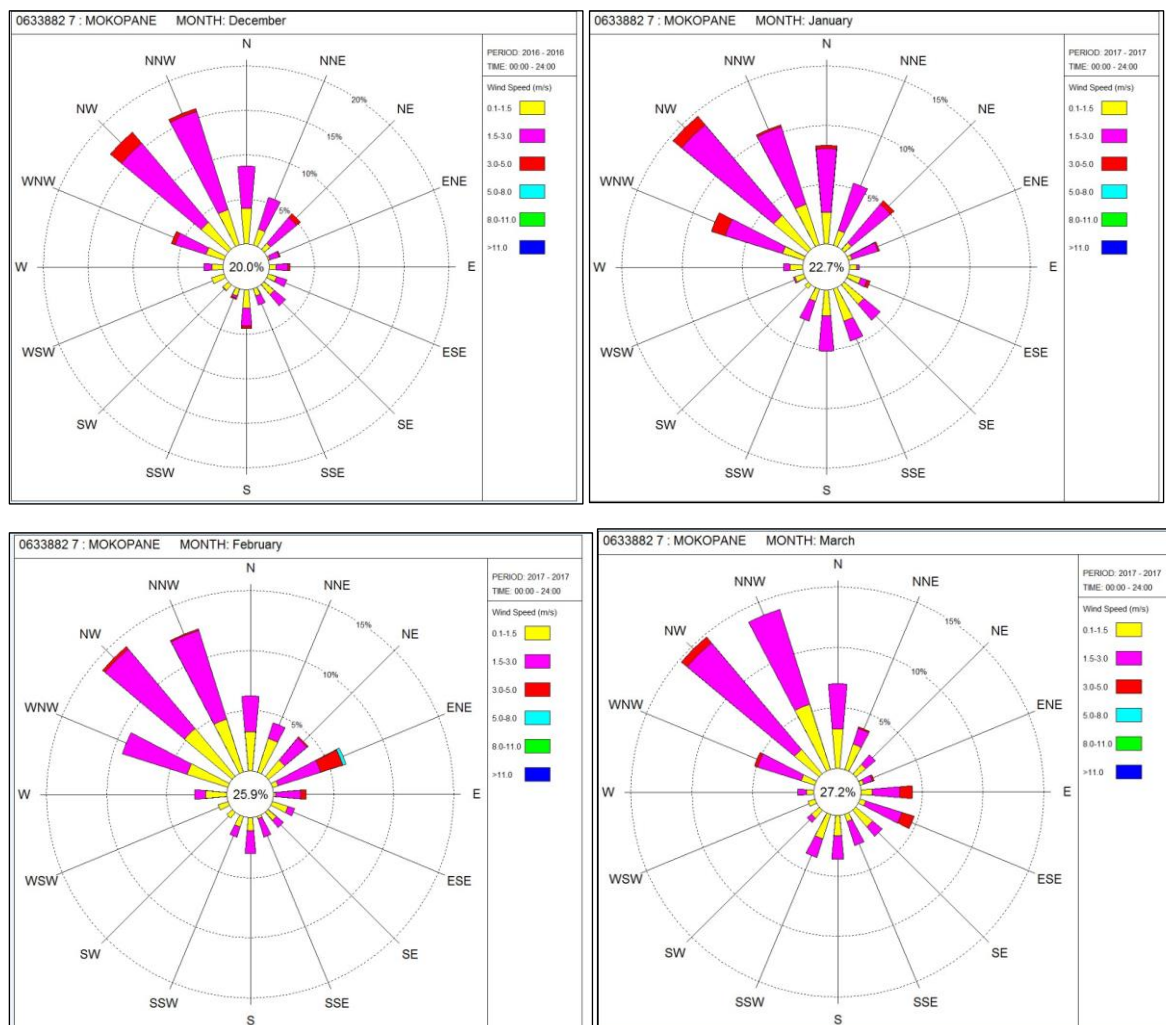


Figure 2: Monthly average wind rose for Mokopane for December 2016, January and February and March 2017 (summer season)

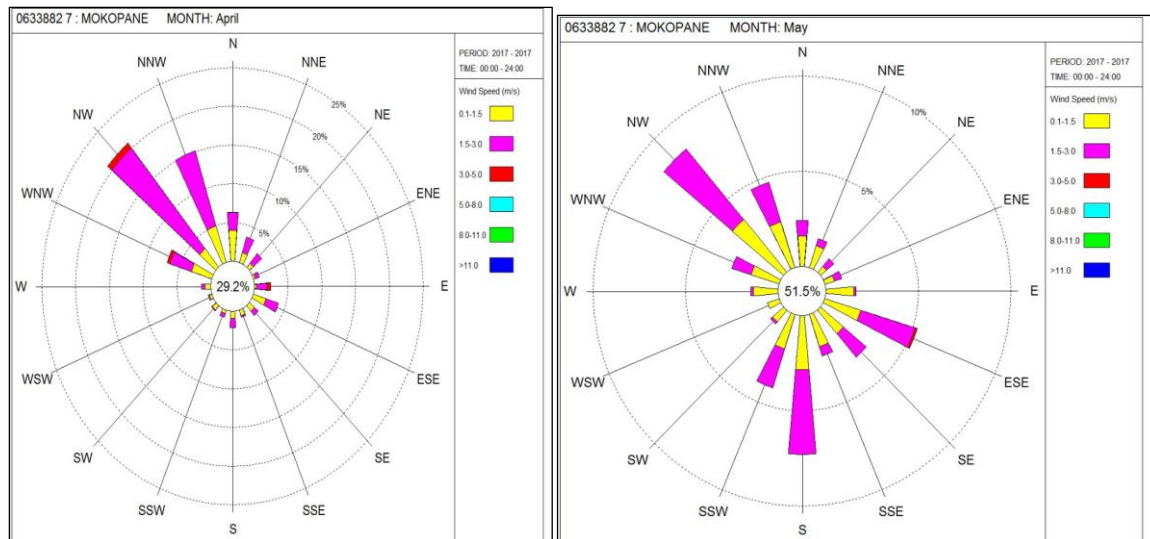


Figure 3: Monthly average wind rose for Mokopane for April and May 2017(autumn season)

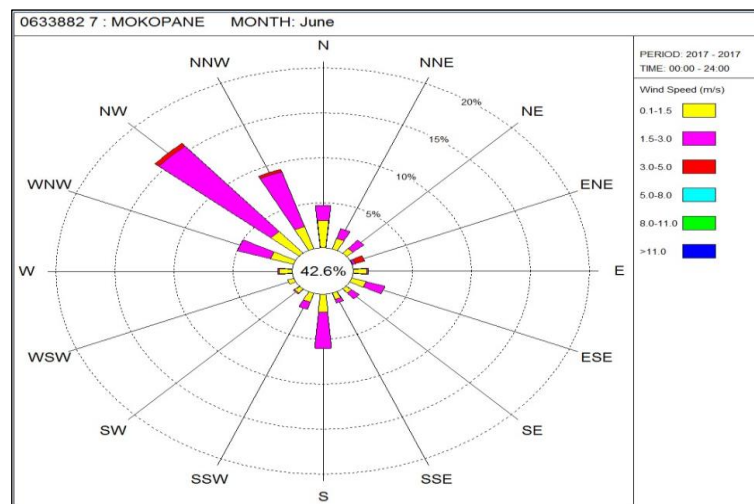


Figure 4: Monthly average wind rose for Mokopane for June 2017(winter season)

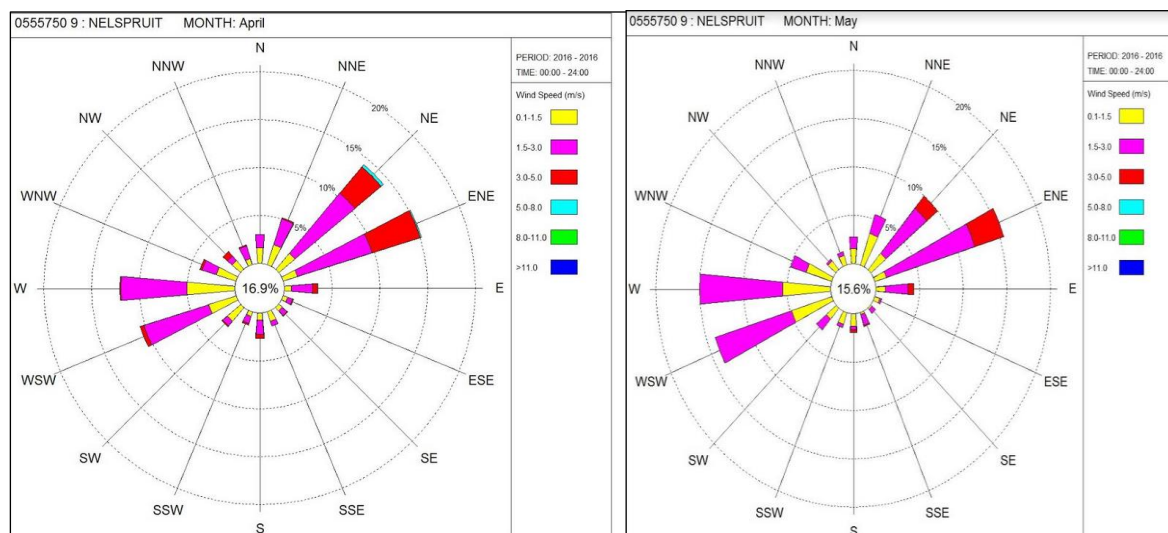


Figure 5: Monthly average wind direction for Nelspruit for April and May 2016(autumn season)

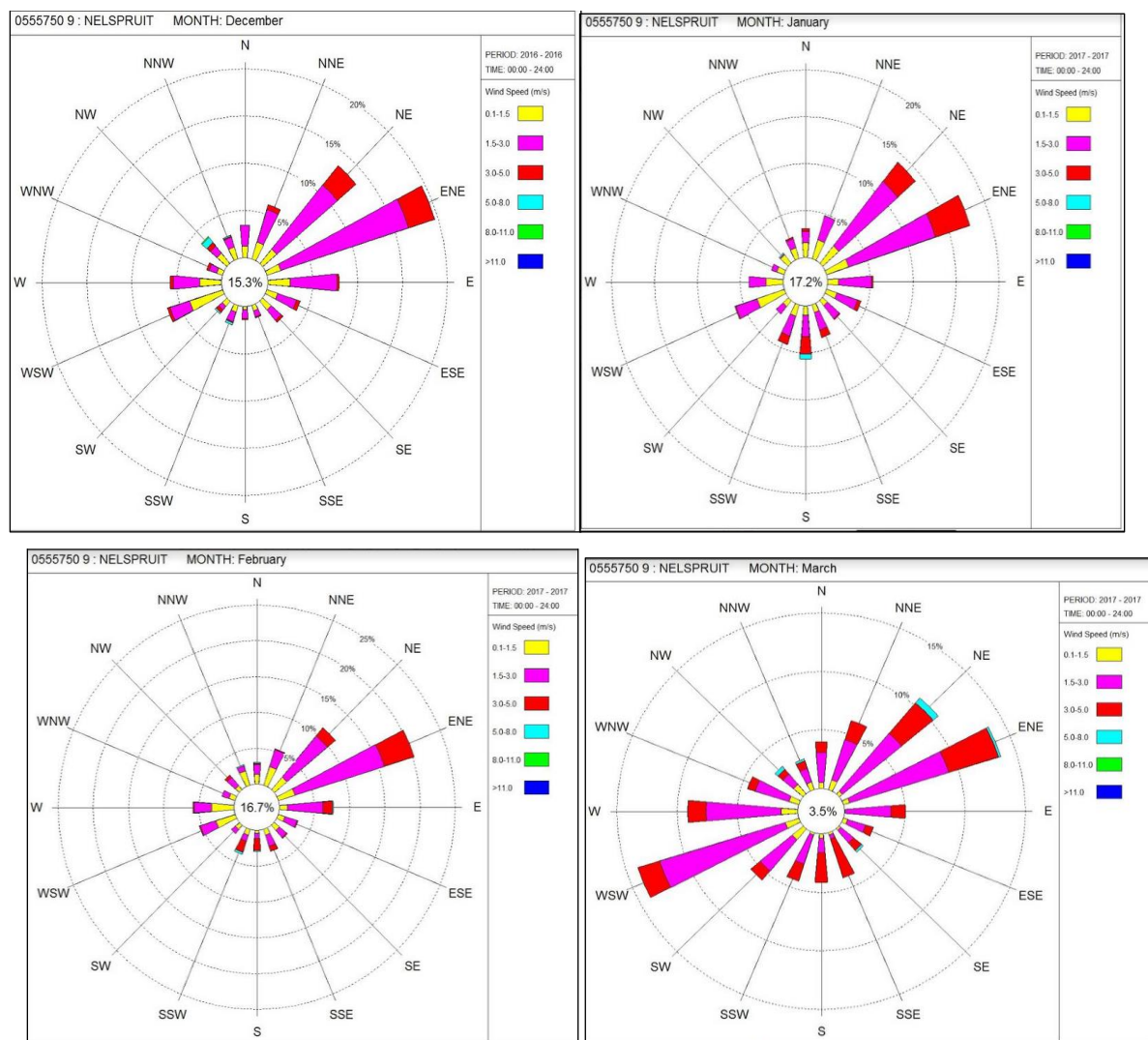


Figure 6: Monthly average wind rose for Nelspruit for December 2016, January, February and March 2017(summer season)

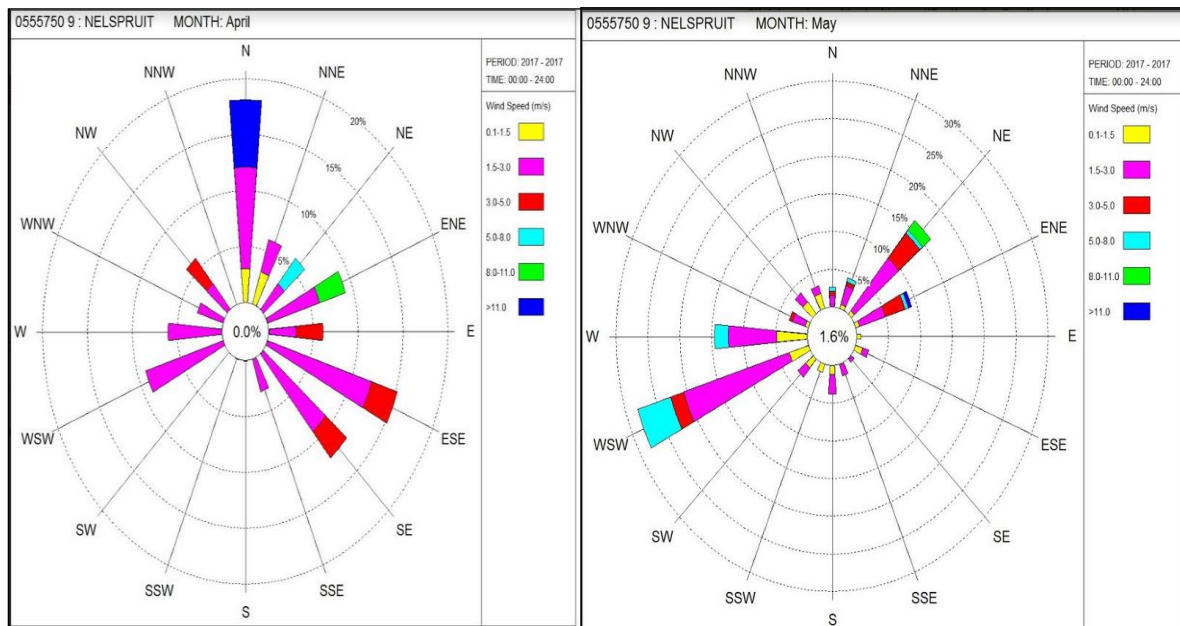


Figure 7: Monthly average wind direction for Nelspruit for April and May 2017 (autumn season)

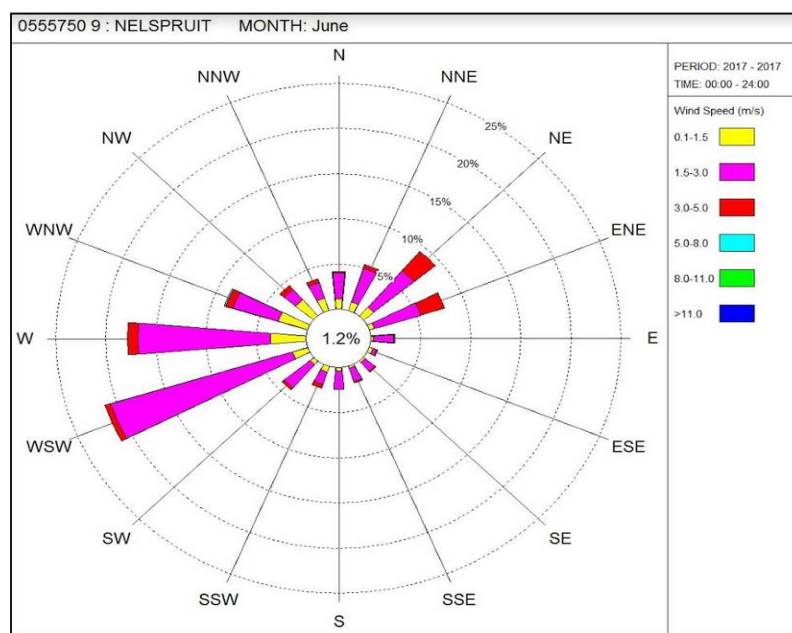


Figure 8: Monthly average wind rose for Nelspruit for June 2017 (winter season)

APPENDIX B: Camera and magnification of SEM-EDS images results

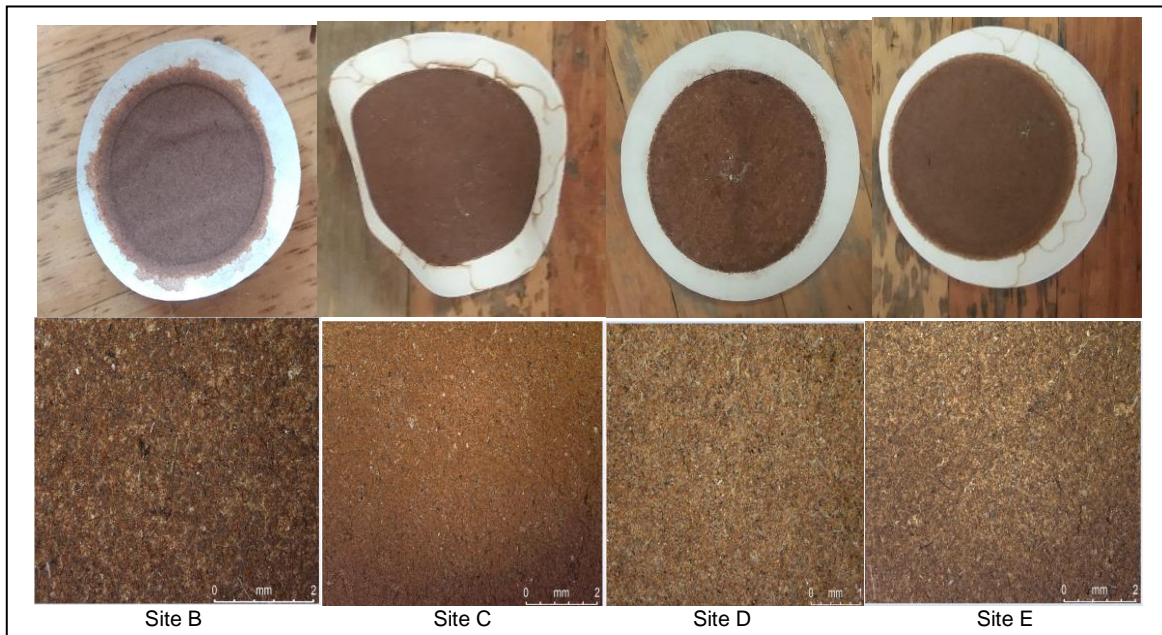


Figure 9: SEM image from filtered dust samples for Limpopo Province

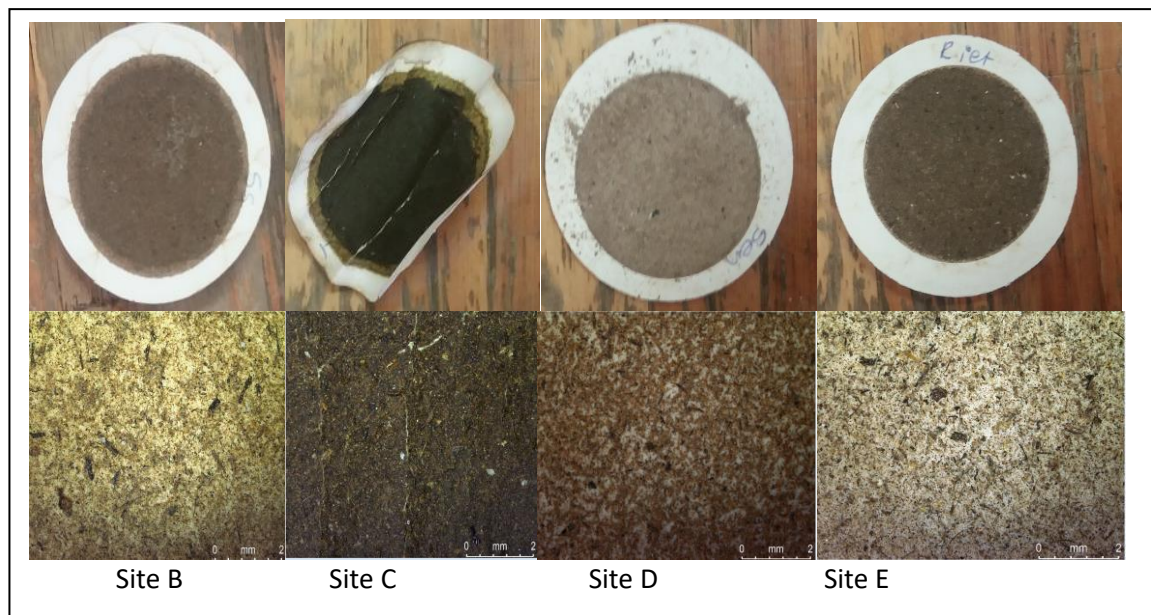


Figure 10: SEM image from filtered dust samples for Mpumalanga Province

APPENDIX B: SEM-EDS results from filtered dust and trapped dust samples for Limpopo and Mpumalanga Provinces

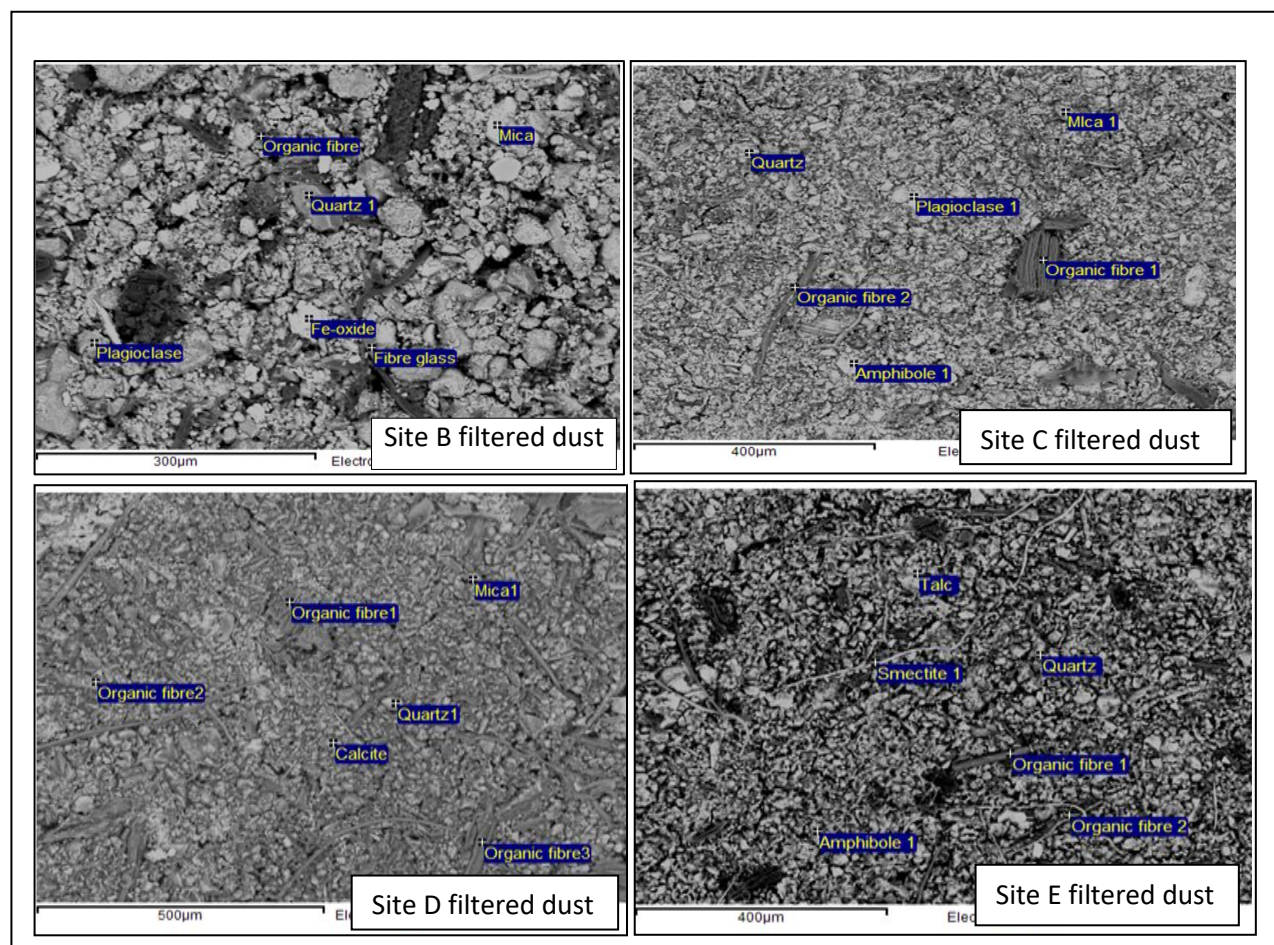


Figure 11: SEM results for Limpopo Province for July 2016

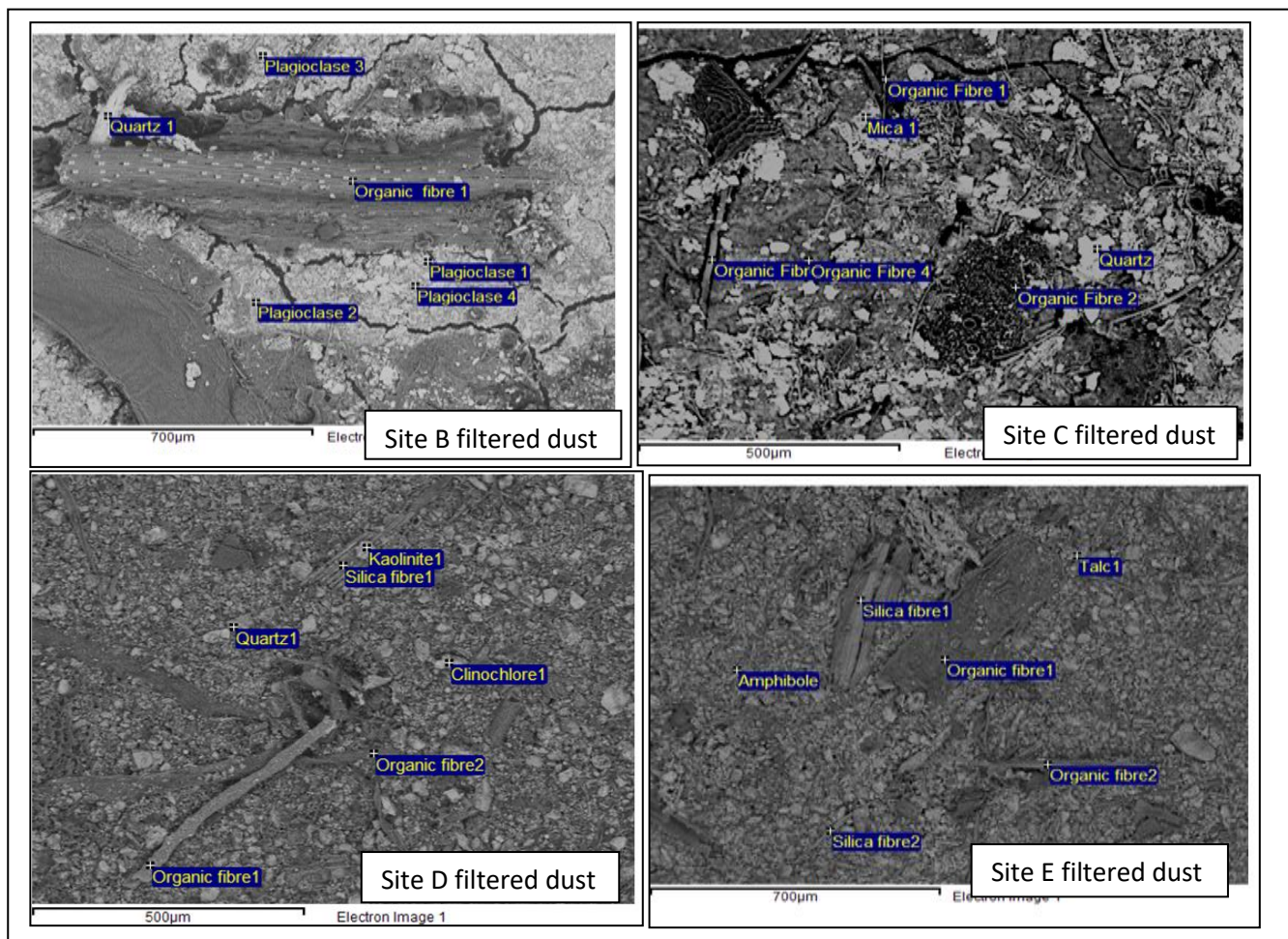


Figure 12: SEM results for Mpumalanga Province for July 2016

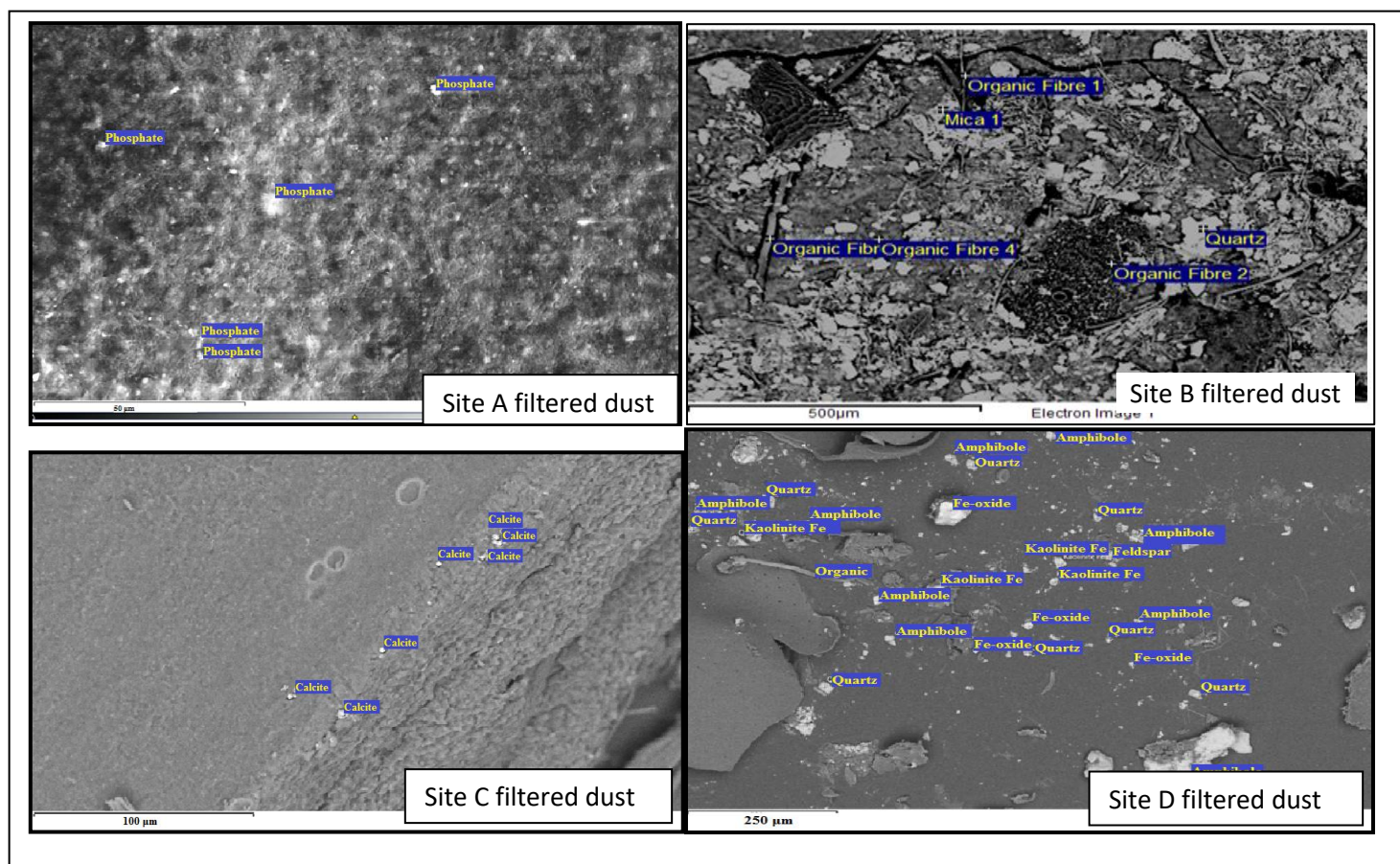


Figure 13: SEM-EDS results for January 2017 for Limpopo Province

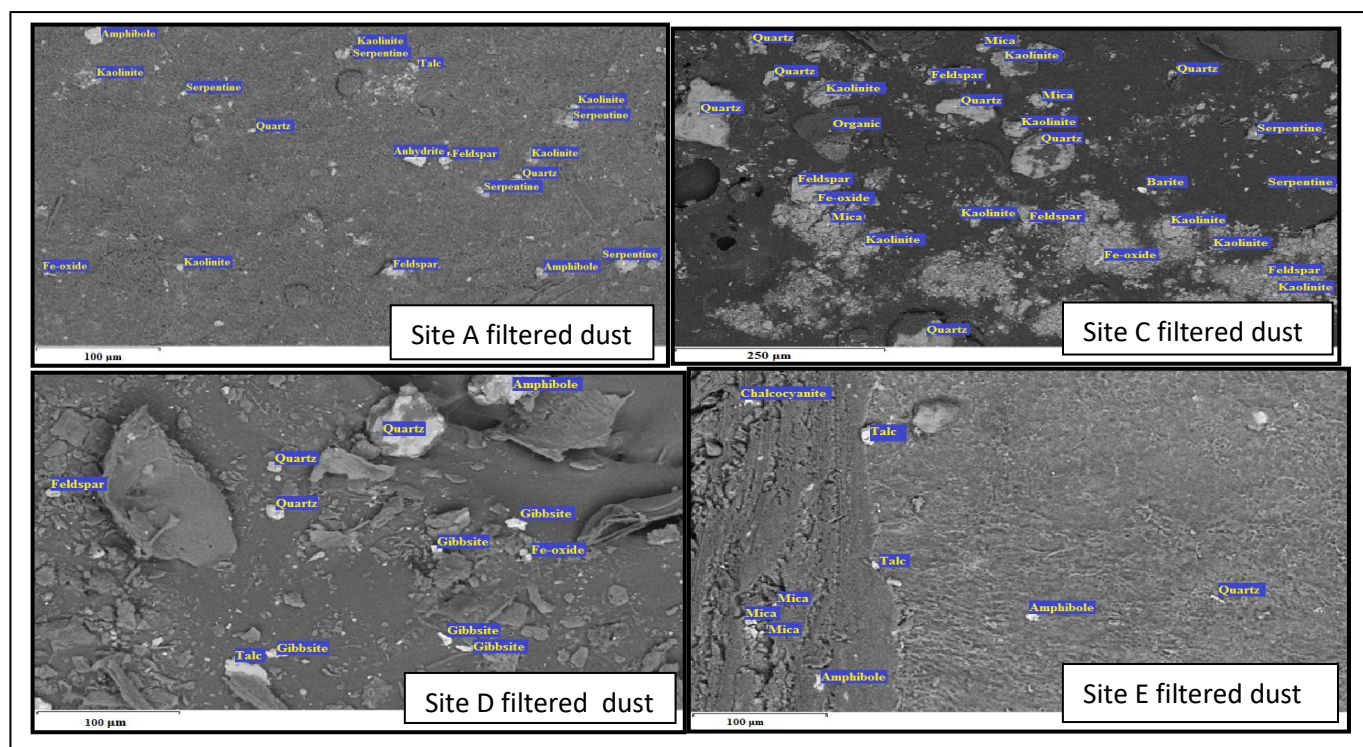


Figure 14: SEM-EDS results for Mpumalanga Province for January 2017

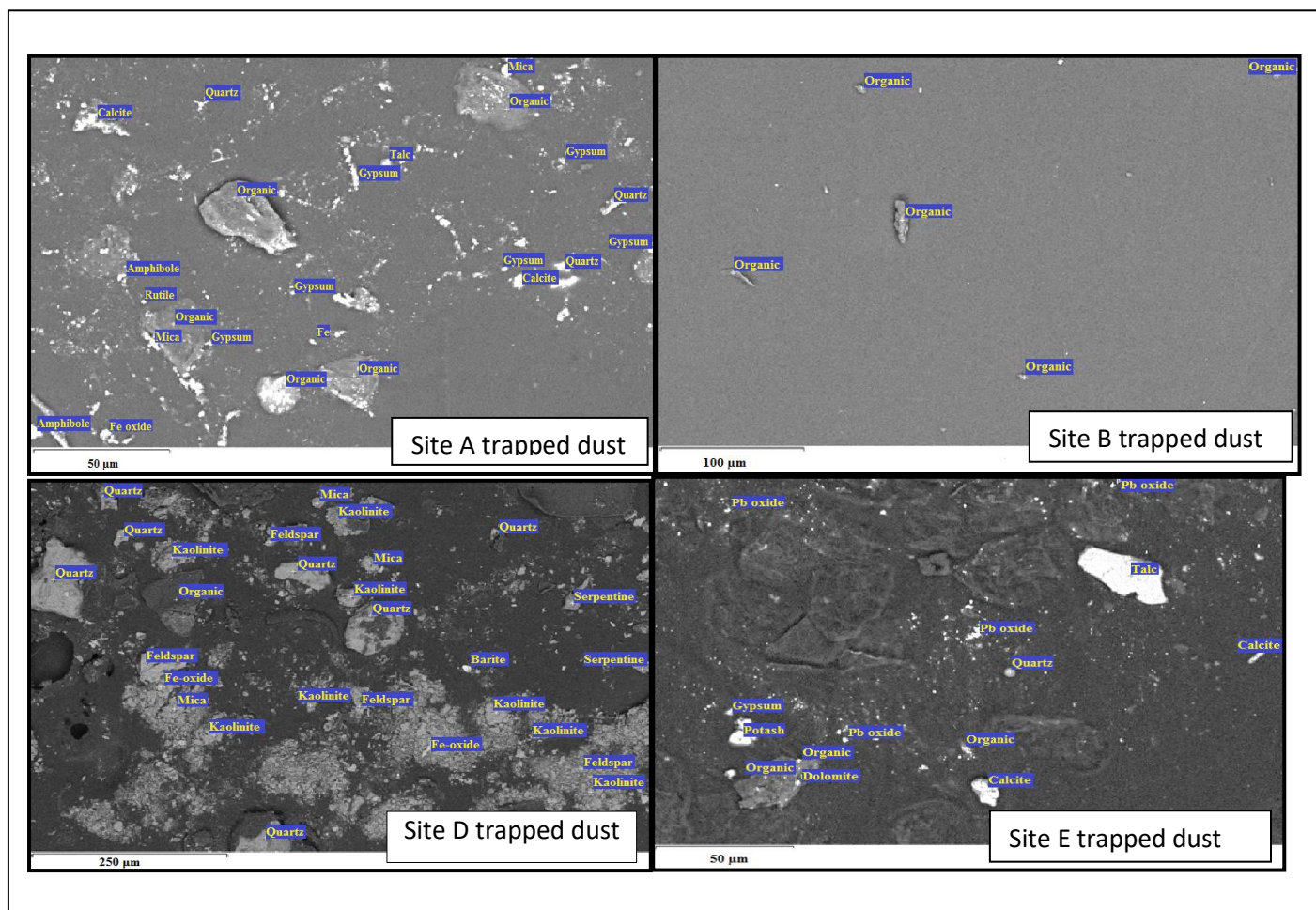


Figure 16: SEM-EDS results for January 2017 for Mpumalanga Province

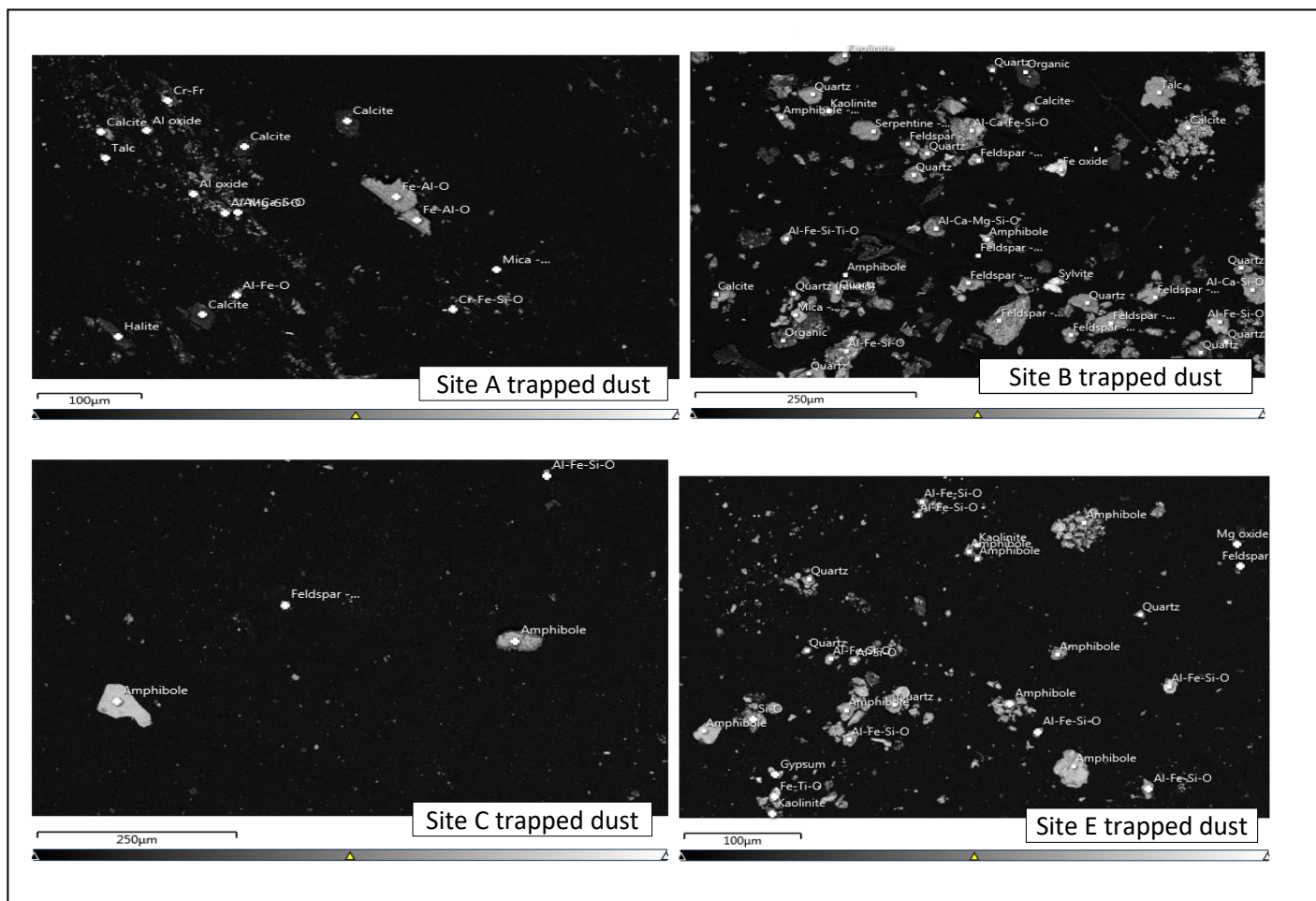


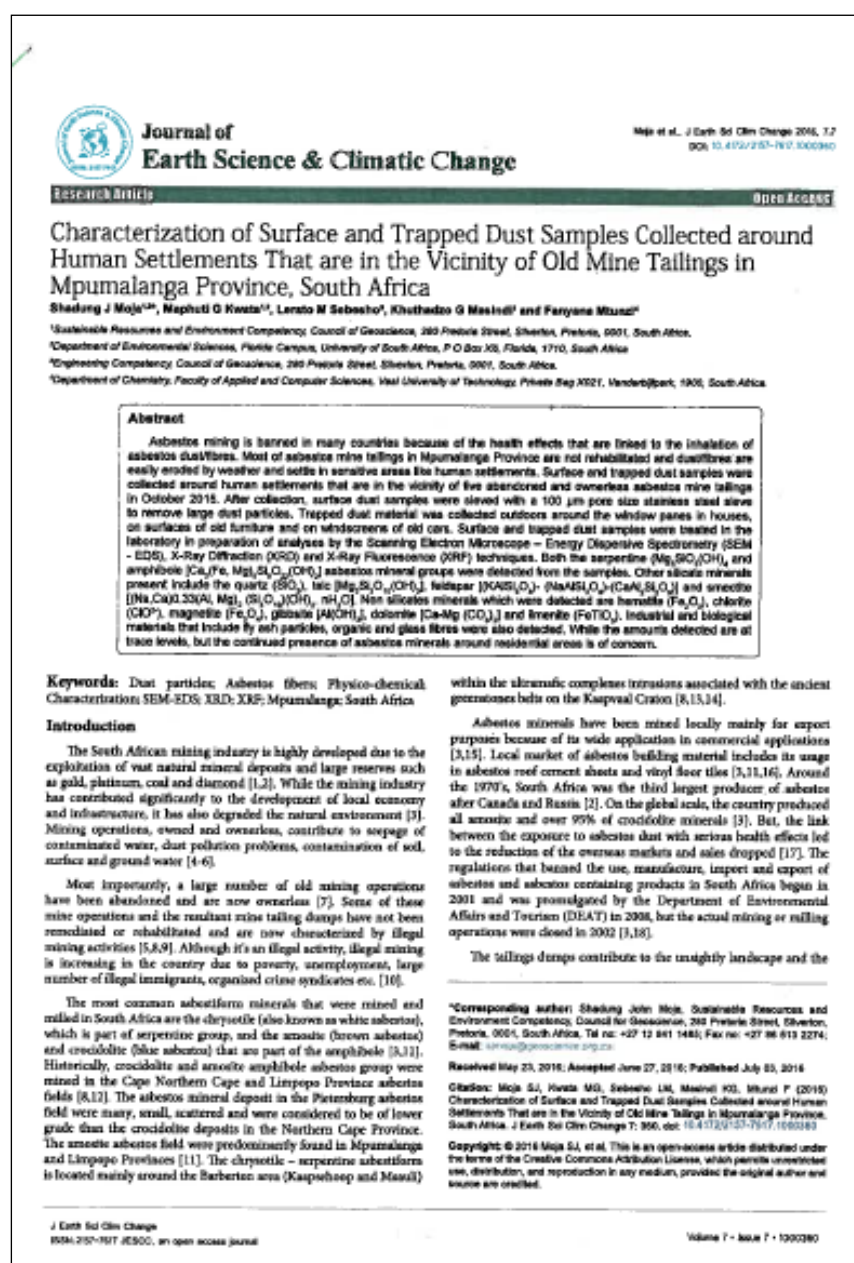
Figure 18: SEM-EDS results from trapped dust samples for July 2017 for Mpumalanga Province

Percentage of asbestos fiber count results for Limpopo and Mpumalanga Provinces

Table 3: Percentage of asbestos fiber count for Limpopo and Mpumalanga Provinces

			Sampling Time				Concentration	
Sites	Dates	Flow rate (l/min)	Minutes (min)	Hours (hr)	Volume	No of Fibers / 200 fields	(f/ml)	(f/m ³)
Limpopo Province								
Site A	17-Jan	2.00	245	4.08	490.00	1	0.000516451	516.451
Site B	17-Jan	2.00	260	4.33	520.00	Sample damaged	-	-
Site C	17-Jan	2.00	155	2.58	310.00	0	0	0
Site D1	17-Jan	2.00	245	4.08	490.00	0	0	0
Site E	17-Jan	2.00	251	4.18	502.00	1	0.000504106	504.106
Mpumalanga Province								
Site A	17-Jan	2.00	245	4.08	490.00	Sample damaged	-	-
Site B	17-Jan	2.00	240	4.00	480.00	0	0	0
Site C	17-Jan	2.00	164	2.73	328.00	0	0	0
			Sampling Time				Concentrations	
Sites	Dates	Flow rate (l/min)	Minutes (min)	Hours (hr)	Volume	No of Fibers / 200 fields	(f/ml)	(f/m ³)
Site D	17-Jan	2.00	242	4.03	484.00	2	0.001045708	1045.708
Site E	17-Jan	2.00	244	4.07	488.00	0	0	0
Limpopo Province								
Site A	17-Feb	2.00	240	4.00	480.00	0	0	0
Site B	17-Feb	2.00	240	4.00	480.00	0	0	0
Site C	17-Feb	2.00	241	4.02	482.00	2	0.001050047	1050.047
Site D1	17-Feb	2.00	240	4.00	480.00	0	0	0
Site D2	17-Feb	2.00	241	4.02	482.00	1	0.000525023	525.023
Site D3	17-Feb	2.00	241	4.02	482.00	1	0.000525023	525.023
Site E	17-Feb	2.00	240	4.00	480.00	0	0	0
Mpumalanga Province								
Site A	17-Feb	2.00	240	4.00	480.00	0	0	0
Site B	17-Feb	2.00	164	2.73	328.00	2	0.001543056	1543.056
Site C	17-Feb	2.00	245	4.08	490.00	0	0	0
Site D	17-Feb	2.00	241	4.02	482.00	0	0	0
Site E	17-Feb	2.00	260	4.33	520.00	0	0	0
Limpopo Province								
Site A	17-Jun	2.00	240	4.00	480.00	11.5	0.006062925	6062.925
Site B	17-Jun	2.00	260	4.33	520.00	3.5	0.001703297	1703.297
Site C	17-Jun	2.00	240	4.00	480.00	Sample damaged	-	-
Site D1	17-Jun	2.00	240	4.00	480.00	10	0.005272109	5272.109
Site E	17-Jun	2.00	240	4.00	480.00	3	0.001581633	1581.633
Site F	17-Jun	2.00	240	4.00	480.00	12.5	0.006590136	6590.136
Limpopo Province								
Kaapsehoop	17-Jun	2.00	240	4.00	480.00	0	0	0
Limpopo Province								
Site A	17-Jul	2.00	240	4.00	480.00	1	0.000527211	527.211

Site B	17-Jul	2.00	240	4.00	480.00	2.5	0.001318027	1318.027
Site D1	17-Jul	2.00	240	4.00	480.00	0	0	0
Site E	17-Jul	2.00	240	4.00	480.00	3	0.001581633	1581.633
Site F	17-Jul	2.00	275	4.58	550.00	2	0.000920223	920.223
Mpumalanga Province								
Site A	17-Jul	2.00	240	4.00	480.00	1	0.000527211	527.211
Site D	17-Jul	2.00	260	4.33	520.00	4.5	0.002189953	2189.953
Site E	17-Jul	2.00	240	4.00	480.00	0	0	0
Limpopo Province								
Site B	17-Sep	2.00	240	4.00	480.00	26.5	0.013802083	13802.083
Limpopo Province								
Site A	17-Oct	2.00	240	4.00	480.00	40	0.020833333	20833.333
Site B	17-Oct	2.00	240	4.00	480.00	4	0.002108844	2108.844
Site C	17-Oct	2.00	240	4.00	480.00	0	0	0
Site D1	17-Oct	2.00	240	4.00	480.00	2	0.001041667	1041.6667
Site E	17-Oct	2.00	240	4.00	480.00	6	0.003125	3125
Mpumalanga Province								
Site A	17-Oct	2.00	240	4.00	480.00	1	0.000520833	520.83333
Site D	17-Oct	2.00	240	4.00	480.00	1	0.000520833	520.83333
Site E	17-Oct	2.00	240	4.00	480.00	0	0	0
Limpopo Province								
Site A	17-Nov	2.00	240	4.00	480.00	3.5	0.001822917	1822.9167
Site B	17-Dec	2.00	240	4.00	480.00	1	0.000520833	520.83333
Site C	17-Dec	2.00	240	4.00	480.00	2.5	0.001302083	1302.0833
Site D1	17-Nov	2.00	240	4.00	480.00	0	-	-
Site E	17-Nov	2.00	240	4.00	480.00	3	0.0015625	1562.5
Mpumalanga Province								
Site A	17-Nov	2.00	240	4.00	480.00	2	0.001041667	1041.6667
Site D	17-Nov	2.00	240	4.00	480.00	4	0.002083333	2083.3333
Site E	17-Nov	2.00	240	4.00	480.00	0	-	-



MEASUREMENT AND CHARACTERIZATION OF DUST-FALL SAMPLES FROM MPUMALANGA PROVINCE, SOUTH AFRICA

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ABSTRACT

Exposure of asbestos dust comes from several sources that include mine dumps, unpaved road trade of asbestos materials, blasting, crushing, grinding and milling activities, as well as spillages from trucks carrying the asbestos materials. The threat to human health is exacerbated by wind blowing over uncovered asbestos dust, making it airborne and inhaled by nearby local communities. The aim of this case study is to measure the dust-fall rates, characterize the dust and determine the metal levels in the resulting filtrate solutions within the Mpumalanga study area. The standard method for collection and analysis of dust-fall rates adopted by the American Standard Test Method (ASTM D 1739, 1970) and the South African National Dust Control Regulations (NDC R 827, 2013) was used. Filtrate solutions generated after filtering the collected falling dust were analyzed with Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) to determine the levels of some trace metals. Dust samples were characterized with a Scanning Electron Microscopy-Energy Dispersive Spectrometry (SEM-EDS) to determine the morphology such as shape, size, length and width of asbestos fibers. Dust-fall rates measured from January to June 2016 were all below the residential standard limit of 600 mg/m²/day at all five sampling sites. Site E was the highest with 478 mg/m²/day measured in May 2016, possibly due to its close proximity to the asbestos mine dump. All trace metals of interest (manganese (Mn), iron (Fe), nickel (Ni), cadmium (Cd) and lead (Pb)) exceeded the local and international standard limits. SEM-EDS results confirm the dominance of silicates minerals that include the serpentine ($(\text{Mg}_3(\text{OH})_4(\text{Si}_2\text{O}_5)_2)$), amphibole ($(\text{NaCa}_2(\text{Mg}_2\text{FeAl})_5(\text{Al}_2\text{Si}_6\text{O}_{22}(\text{OH})_2)$), quartz (SiO_2), plagioclase ($\text{NaAlSi}_3\text{O}_8$), kaolinite ($\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$), $\text{Fe}^{2+}\text{Al}(\text{Si}_4\text{Al})\text{O}_{10}(\text{OH})_2$, feldspar (KAlSi_3O_8) and mica ($\text{KAl}_2(\text{Si}_2\text{Al})_2(\text{OH})_2$). The presence of poisonous metals and asbestos fibers could have negative health impacts to the exposed individuals.

Keywords: asbestos mining, asbestos dust, dust fall rates, mine dumps, NDC R 827-2013, minerals, ASTM D 1739-1970, SEM-EDS, ICP-MS.

1 INTRODUCTION

Asbestos mining has left behind major environmental and health challenges. Wind blowing across the old and abandoned mine dumps transport dust to nearby communities. Asbestos is one of the oldest mineral mined in South Africa (Hart [1]). The risk of being exposed to asbestos dust is increased by the close proximity of human settlements to areas where asbestos minerals were mined and milled (Muculloch [2]). Asbestos materials were used by the rich and royals in the past to preserve the ashes after cremation (Abratt et al. [3]). Inhalation of asbestos dust or fibers is known to cause lung diseases such as asbestosis (scarring of the lungs), lung cancer and mesothelioma (a malignant and fatal tumor that grows on the lining of the lung) (Felix et al. [4]). The purpose of this study is to measure dust fall rates and characterize the resulting dust and filtrate solution samples collected within residential areas that are close to un-rehabilitated mine dumps around the Mpumalanga Province with the intention of assessing the asbestos pollution levels.



Characterization of Settleable Dust and Surface Dust Samples from the Old and Abandoned Asbestos Mine Dumps in the Limpopo Province, South Africa

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Abstract

Old and abandoned (O&A) mine dumps refer to the asbestos mine dumps which were operated when environmental management was not regulated in the country and owners of mining rights could no longer be traced. These mine dumps are not being maintained or rehabilitated and the associated impacts are not being mitigated and managed.

The aim of this research is to monitor, measure and characterise settleable dust and surface dust samples collected around local communities in the vicinity of old and abandoned asbestos mine dumps. The local standard method for collection and analysis of settleable dust (the South Africa National Dust Control Regulations 627 of 2013) was used in this research. Surface dust samples were collected using standard method in January, April and July 2016. Settleable dust samples were collected from January 2016 to July 2016 around five sampling sites in Limpopo Province. The samples were prepared for analyses.

The settleable dust rates are below the residential limit of 600 mg/m²/day. The analytical measurements confirm the presence of silicates, minerals, amphibole and serpentine asbestos minerals. SEM-EDS results tested positive for amphibole and serpentine asbestos minerals. The continued presence of amphibole and serpentine asbestos mineral in Limpopo Province is cause of concern.

Keywords: Settleable dust; Surface dust; XRF; SEM; XRD; Limpopo province; South Africa

Introduction

Mining in South Africa is the leading force behind the history and development of the local economy [1]. Gold, diamonds, coal, iron are the major contributors of the South Africa's mining economy. Local mining sectors contributed up to 65% to the Gross Domestic Products [2-4]. Mining in South Africa has resulted in environmental legacies such as acid mine drainage (AMD) and D&O mine dumps which contributes to environmental degradation and health challenges. The government has begun processes to mitigate and rehabilitate the AMD and D&O mine dumps in an attempt to reduce associated impacts.

Asbestos mining in South Africa started in 1860's and it has left major environmental and health problems [5]. Old and abandoned asbestos mine dumps which are not rehabilitated contribute to the asbestos contaminated dust pollution that is experienced in surrounding areas [1]. Historically, asbestos was mined to manufacture building materials (such as cheap asbestos roof sheets and material used for producing ceilings) which are now linked to health problems [6]. Despite the banning of asbestos mining, illegal asbestos mining operations continue to produce the deadly asbestos dust found everywhere on the ground [7]. The short asbestos fibres had no commercial value and were dumped and made heaps of mine waste.

South Africa has the highest mesothelioma conditions which occur after inhalation of short asbestos fibres [8]. After inhalation, the small needle-like fibres would pierce the lung membrane and remain lodged for a long time causing inflammation and eventually cancer. Health effects are associated with dust particles with diameters below 25 µm because they enter the mouth, nose and the gas exchange regions of lungs readily during inhalation. Dust with particle diameters greater than 25 µm is called nuisance or annoyance dust and is associated with public perceptions where exposed individuals would complain [9]. The

purpose of the study was to measure long term settleable dust rates, the geochemistry, mineralogical, morphological composition and levels.

Experimental Design and Methodology

Study area, geology and sampling points

The study took place within the following five human settlements (Ga-Maleming Village, Ga-Malefe- Mathabats Village, Fenge and Tsung Village) located in the northern province of Limpopo in South Africa. Site 1 is fully rehabilitated and Site A, C, D and E are partially rehabilitated. These human settlements are located near the old and abandoned asbestos mine dumps. The province has bushveld, majestic mountains, primeval indigenous forest, unspoiled wilderness and panoramas of farmland [10]. The geology of the region contains the Transvaal and Chuanaport group; carbonate rock formation (contains iron and magnesium embedded in the rocks) form part of the dolomite series in succession near the top, which is followed by carbonaceous rock formation [11]. Most rocks in the province belong to the Malmani SubGroup and Fenge formation. The most common rocks found in the province are shale, dolomite, chert, quartzite, conglomerate, breccia

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A Mineralogy Study from Settleable Dust Samples in Mpumalanga Province, South Africa

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Abstract

Exposure to asbestos fibers pose serious health problems which are exacerbated by wind currents and by rain water that transports fibers from asbestos mine dumps to nearby residential areas. Most of asbestos mine dumps in Mpumalanga Province are old, ownerless and not rehabilitated. The aim of this pilot study is to characterize the captured settleable dust samples. The two Sites, A and B which were selected for monitoring purpose are located about 20 km away from Mbombela, the capital city of the province. The South African National Dust Control Regulations (SANDOR) 827 of 2003 method was used to collect settleable dust around residential areas that are within 2 km of the asbestos mine dump sources in July 2015 and July 2016. The samples were chemically treated and characterized to identify the type of minerals present and to determine the morphological composition with an XRD and the SEM-EDS analytical techniques respectively. The XRD and SEM-EDS results at Site A confirm the presence of serpentine (28% m/m), organic (4% m/m) and quartz (31% m/m) minerals. Site B contain 35% m/m of serpentine, 10% m/m of amphibole, 37% m/m quartz, 21% m/m organic and 10% m/m fiber glass.

Other minerals detected at both sites were the calcite, k-feldspar, plagioclase, mica and smectite. The SEM-EDS analyses confirm that fiber glass, organic and amphibole are the longest particles/fibers with length of 485 µm, 100 µm and 84 µm respectively. The presence of asbestos dust around the residential areas highlights the possible environmental risk to those who are exposed.

Keywords: Old and ownerless; Rehabilitation; Asbestos dump; Settleable dust fall; SEM-EDS; XRD; Surface dust

Introduction

Mining of asbestos in South Africa started in the 1900's and ceased in 2002 because of environmental and health reasons. Large operations of asbestos mining in South Africa were in Northern Cape, Limpopo and Mpumalanga Provinces in this research their focus will be for Mpumalanga Province. Asbestos products were used for roofing of the houses and manufacturing of brake pads for vehicles [1]. Asbestos mine dumps of concern are unrecycled and are close to residential areas. Asbestos particles are microscopic in size and could be lifted from the ground based sources by wind erosion or during excavation processes [2]. Asbestos mine dumps have left major environmental and health problems. Even today there are people suffering from the exposure of asbestos dust contaminated with asbestos dust. Asbestos dust contaminated with asbestos is transported from old and ownerless asbestos mine dumps to the residential areas [3]. Even though asbestos mining was banned in South Africa, there is still illegal mining operations in the asbestos fields continuing to produce toxic dust [4]. Large quantities of asbestos in South Africa were used for building with little knowledge about the nature of the commodity. The asbestos mine dumps are 5 km away from the residential areas and the height is from 20m to 50m. The exposure of asbestos mine dumps dispersed to the nearby residential areas has caused high mortality. The exposure and danger of asbestos dust was unknown people living nearby asbestos mine dumps started to get sick with respiratory disease which

could not confirm the asbestos dust disease known to be mesothelioma, lung cancer and asbestosis, etc. The method used to mined asbestos was through milling, open cast, underground and crushing which contributed to exposure of asbestos to nearby residential areas through wind blowing. The purpose of the research is to monitor and measure settleable dust rates and characterised surface dust samples around some old and ownerless asbestos mine dumps in the vicinity of residential areas. The type of the samples collected are dust fall using single dust bucket unit and surface dust samples using a brush, dust pan, zipper plastic to determine the shape, size, width, length and type of asbestos detected. This paper reports the dust rates, mineralogical and morphological data after analysing the settleable dust collected in the laboratory.

Materials and Methods

The study area, geology and sampling points

This pilot study took place in the north-eastern part of South Africa within residential areas around Ndapruat, Mafikeng and Bedyllais towns which are within 2.0 km of the asbestos mine dump point sources Mbombela is the capital city of the Mpumalanga Province and is a grassland that is characterized by many pine trees, eucalyptus and mountainous scenery. The province's geology is composed of the Tarkastad and Koonapoor Group and Transvaal Super Group with

A Geochemical and Morphological Study from Dust Samples Collected near Former Asbestos Mining in Limpopo Province, South Africa



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Abstract

The physical characteristics and composition of dust material are essential in the study of soil contamination. The aim of the study is to determine the possible asbestos contamination in dust samples collected both outside and inside of houses in villages that are close proximity to former asbestos mining areas. Asbestos is a silicate mineral that was mined in South Africa, but its mining was ceased in 2002 due to human health effects associated with inhalation. In January 2017 outside surface dust samples were collected in yards with a brush and plastic dust pan, sieved on site with 1.8 mm pore size stainless steel sieve to remove large particles and put into a labeled zipper plastic for storage. Trapped dust samples were collected on pieces of sticky tapes on hard surface both indoor and outdoor of houses and stored in sealed containers. The geochemical and morphological data were generated using (XRF) X-ray fluorescence and (SEM-EDS) Scanning Electron Microscopy - Energy Dispersive Spectrometry presented in the study is for January 2017. The samples were chemically treated and coated with carbon before the analysis commenced. The main finding from this pilot study that reported amphibole silicate asbestos mineral was detected at all the five sites. Previous studies have reported some of the dangers of inhaling asbestos fibres to include inflammation of the affected lung tissue, lung diseases and cancer of the lung tissue. Thus, the exposure to asbestos pollution should be eliminated or minimized.

Keywords: Surface dust; Trapped dust; Asbestos; Former mining areas; XRF, SEM-EDS

Introduction

Mining of asbestos has left behind health and environmental problems [1]. Historically the asbestos materials were used for building roof, ceiling, and brake pads for vehicles [2]. While asbestos mining began little was unknown about the danger of the mineral due to the human and health effects [3]. Besides the banning of asbestos in 2002 is still contributing to the human health effects. Asbestos fibres mass is less 1 g which can be easily getting lifted in the air and suspended until transported to the close local communities [4]. There were cases of asbestos related diseases on the following mesothelioma, lung cancer and asbestosis which contributed to the high mortality due to the asbestos mineral "miracle mineral" [5]. The purpose of the study is to determine the geochemical and morphological composition from surface dust and trapped dust samples collected in the local communities in the vicinity to the derelict and abandoned mine dumps in Limpopo Province.

Experimental Procedure

Study Area

The study was undertaken within the following five local communities (Ga-Mafemang Village, Ga-Mafefe - Nachabata

Village, Penge and Young Village) located in Limpopo Province (formerly Northern Province) in South Africa. Site B is fully rehabilitated and Sites A, C, D and E are partially rehabilitated. These communities are located near the old and abandoned asbestos mine dumps. The province has bushveld, majestic mountains, primeval indigenous forest, unspoiled wilderness and patchwork of farmland [6]. The geology of the province contains the Transvaal and Chuniespoort group; carbonate rock formation (contains iron and magnesium embedded in the rocks) form part of the dolomite series in succession near the top, which is followed by carbonate rock formation [7]. Most rocks in the province belong to the Mafumi Subgroup and Penge formation. The most common rocks found in the province are shale, dolomite, chert, quartzite, conglomerate, breccia and diamicite [8]. Penge is an old town situated approximately 40 km north-west of Burgersfort, in the Greater Tlokweng Local and Greater Sekhukhune District Municipalities. The asbestos mines were located south of the Pietersburg asbestos fields [9] and extend in an 80 km arc from Mafesdrift in the north-west to the confluence of the Olifants and Steelpoort Rivers in the southeast [1]. The Penge asbestos mine and village are located in the south-eastern extremities of the Pietersburg asbestos field [10]. Ga-

A PHYSICO-CHEMICAL STUDY OF DUST SAMPLES FROM THE DERELICT AND OWNERLESS ASBESTOS MINE DUMPS IN MPUMALANGA PROVINCE, REPUBLIC OF SOUTH AFRICA

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ABSTRACT

Asbestos is generally defined as a group of naturally occurring fibrous, silicate mineral that is abundant on the crust of the Earth. Despite the cessation of asbestos mining due to associated health effects in the Republic of South Africa in 2001, there is still a concern about possible environmental exposure to asbestos fibres. This paper reports the dust fall rates for a period of six months from January 2017 to June 2017 using the American Standard Test Method, ASTM D1739 of 1970 at five sampling sites that are within the local communities that are close to the derelict and ownerless asbestos mine dumps in Mpumalanga Province. This method is the recommended method of collection and analysis of dust fall rate in South Africa. After filtration, dust fall rates were determined gravimetrically. Filter papers containing dust fall samples were further analysed using the Scanning Electron Microscope – Energy Dispersive X-ray (SEM – EDX), X-Ray Diffraction and Fluorescence (XRD and XRF) techniques. The amount of the serpentine asbestos group vs amphibole asbestos group obtained were 23 and 3 %/m at site A, 5 and 2 %/m at site B, 15 and 0% %/m at site C, 36 and 7 %/m at site D, as well as 7 and 0 %/m at site E. Other minerals detected in random order include feldspar, kaolinite, quartz, mica and talc. The non-silicate minerals detected were ilmenite, metallic and organic and different types of amphibole: actinolite, barroisite, ferri-magnesianamphibole, grunerite, tremolite, winchite and feldspar; albite, andesine, anorthite, bytownite, labradorite, microcline, oligoclase, andesine, and sanidine. Most particles dust with shapes that include granular, sponge like, spiral, semi rectangular and semi triangular. The length to width ratios of the serpentine asbestos group ranged from 2.1 to 6.1, while the amphibole ratios were about 3:1 to 5:1. The continued presence of asbestos group minerals in inhalable fractions of airborne dust material is worrying and should be mitigated accordingly.

Key words: Dust fall, asbestos, minerals, physico-chemical, and characterization, SEM, XRD.

1 INTRODUCTION

Asbestos mining around the world has caused environmental and human health concerns [1]. Asbestos is generally defined as a group of naturally occurring fibrous, silicate minerals that is abundant on the crust of the Earth [2], [3]. Asbestos mineral is known as a "miracle mineral" needle like in shape [4]. In the past, little was known about its health and environment effects [5]. Since the banning of asbestos mining in South Africa in 2002 and in other countries the effects are still visible and continue to impact the health and environment negatively [6]. Asbestos mine dumps in Mpumalanga Province are not rehabilitated and dust particles / fibres could easily be lifted and transported by wind, and then settle in sensitive areas like nearby

A STUDY ON TRAPPED DUST AND DUSTFALL SAMPLES FROM REHABILITATED AND NON-REHABILITATED ABANDONED ASBESTOS MINE DUMPS IN THE NORTHERN CAPE PROVINCE, SOUTH AFRICA

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ABSTRACT

Abandoned asbestos mine dumps continue to have an effect on human health notwithstanding the banning of asbestos mining in South Africa in 2002. Asbestos mine dumps contribute to dust pollution, especially non-rehabilitated ones. Dust particles from these mine dumps find their way to nearby human settlement and cause a health risk. Respiratory problems such as lung diseases are a result of inhaled suspended asbestos fibres/dust in the air. For the purpose of environmental remediation, rehabilitated and non-rehabilitated sites around Kuruman and Prieska in the Northern Cape Province respectively were selected to compare the presence of asbestos and effectiveness of rehabilitation. Measuring and monitoring dustfall was conducted within 5 km radius from the asbestos mine dump to the nearest human settlement. Characterisation was done for both trapped dust and dustfall samples. Dustfall samples were collected and measured using a 2 m stand with single open half-filled bucket of deionized or distilled water. Trapped dust samples were collected indoors and outdoors on photo frames, window frames, old furniture and roofing tops using the sticky tape. X-ray Diffraction (XRD) technique was employed for mineralogical composition on both samples. Mineralogical and morphological characterisation was further validated using Scanning Electron Microscope with Energy Dispersive Spectroscopy (SEM-EDS). The XRD results show significant amount of amphibole $[(\text{Ca}_2\text{Fe,Mg})_7\text{Si}_8\text{O}_{22}(\text{OH})_2]$ asbestos mineral group. Traces amount of serpentine $[\text{Mg}_3\text{Si}_2\text{O}_5(\text{OH})_4]$ asbestos mineral group were detected by XRD but could not be confirmed using SEM-EDS. However, both XRD and SEM-EDS results confirmed the presence of amphibole asbestos mineral group. Other silicate minerals detected include quartz, talc, mica, plagioclase and feldspar. Detected non-silicate minerals include calcite, amethyst and traces of hematite. Exposure of amphibole asbestos mineral group and silicate minerals to human continues to be a major health concern.

Keywords: Asbestos mine dump, asbestos fibres, dustfall, trapped dust, composition, characterisation, XRD, SEM-EDS

Asbestos Fibre and Mineral Counts from Filtered Dust Collected in Human Settlements Asbestos Mine Dumps in Mpumalanga Province, Republic of South Africa

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DOI:10.24966/ESCR-5020/S1003

Abstract

Dust generation sources come from mining sites including mine dumps, crushing, hauling, grinding and offloading of waste material from open pit and underground operation and non-operations, movement of trucks on unpaved roads, etc. Many mine dumps in South Africa ~~are not rehabilitated~~ due to the possibility of re-mining in the case of asbestos dumps or have been abandoned by previous owners for different reasons. Some of the reasons for abandonment include bankruptcy, ineffective enforcement, lack of financial assurance, minimal penalties for ~~non-compliance~~ and commodities like gold, asbestos and coal are affected. Historically, only long asbestos fibres ~~were used~~ for manufacturing purpose. While short fibres were unwanted and dumped with other waste material ~~and~~ today heaps of such waste materials are the source of airborne asbestos fibre pollution. Asbestos mining in South Africa ~~was ceased~~ in 2002 mainly due to the associated human health problems. This study aims to measure the level of asbestos fibre concentration in airborne dust samples using Phase Contrast Microscope (PCM). The % mineral count in filtered dust samples were analysed using Scanning Electron Microscope-Energy Dispersive Spectrometry (SEM-EDS) techniques. The AirCon 2 sampler was used to collect airborne asbestos with an ~~air flow~~ rate of 2.0 L/Min for 24 hours. Filtered dust fallout samples were collected using single dust bucket unit exposed onsite for a period of 30 days following the local Dust Control Regulations. The results from July to December 2017 shows the following concentrations Site A with 572 f/mL, Site B with 2.189 f/mL, in July 2017, in August 2017 at Site D with 572 f/mL, Sites A& E with 1.845 f/mL and from October to December 2017 sample damaged. SEM-EDS results show that amphibole asbestos mineral group detected at all the sites and other silicate mineral detected were quartz, and feldspar. Organic material ~~was detected~~. Serpentine asbestos mineral group ~~was not detected~~ at all the sites.

Keywords

Asbestos fibre count; Former asbestos mine dumps; Mineral count; Mpumalanga Province

APPENDIX D : Turnitin Reports

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Nelson, G. J. Murray, and J. I. Phillips, "The Risk of Asbestos Exposure in South African Diamond Mine Workers", Annals of Occupational Hygiene, 2011.

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APPENDIX E: Ethical clearance documents

UNISA 

CAES RESEARCH ETHICS REVIEW COMMITTEE

Date: 04/05/2016

Ref # : 2016/CAES/058
 Name of applicant: **Ms M. Kamo**
 Student # : 57541558

Dear Ms Kamo,

Decision: Ethical Approval

Proposal: Characterisation of asbestos mine dump samples from some South African abandoned and derelict mines

Supervisor: Prof S.J. Hogg

Qualification: Postgraduate degree

Thank you for the application for research ethics clearance by the CAES Research Ethics Review Committee for the above mentioned research. Final approval is granted for the duration of the project.


The application was reviewed in compliance with the Unisa Policy on Research Ethics by the CAES Research Ethics Review Committee on 03 May 2016.

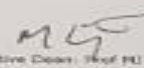
The proposed research may now commence with the proviso that:


- 1) The researcher/s will ensure that the research project adheres to the values and principles expressed in the UNISA Policy on Research Ethics.
- 2) Any adverse circumstance arising in the undertaking of the research project that is relevant to the ethicality of the study, as well as changes in the methodology, should be communicated in writing to the CAES Research Ethics Review Committee. An amended application could be requested if there are substantial changes from the existing proposal, especially if those changes affect any of the study-related risks for the research participants.
- 3) The researcher will ensure that the research project adheres to any applicable national legislation, professional codes of conduct, institutional guidelines and scientific standards relevant to the specific field of study.

Note:
The reference number (top right corner of this communiqué) should be clearly indicated on all forms of communication (e.g. Webmail, E-mail messages, letters) with the intended research participants, as well as with the CAES RERC.

Kind regards,


 Signature
 CAES RERC Chair: Prof S.J. Kempen


 Signature
 CAES Executive Dean: Prof M. Lirington


 Approval template 2014

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Letters for access to CGS Laboratories for analysis

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Council for Geoscience
Leaders in Applied Geoscience Solutions

TO: Prof E. Kempen: Chair of Ethics Committee, CAES, University of South Africa
FROM: Miss Maphuti Kwata (PhD Candidate -Student Number: 57341559)
DATE: 09 December 2015
RE: PERMISSION TO ALLOW MISS MG KWATA TO USE THE COUNCIL FOR GEOSCIENCE
LABORATORIES / FACILITIES TO CONDUCT HER PHD STUDY

Dear Madam,

Ms. Maphuti Kwata is registered for a PhD Degree within the Environmental Sciences Department at UNISA under the supervision of Dr Si Moja. Her topic is aligned to her work at the Council for Geoscience and it involves monitoring the levels and quality of dust and air quality within mine related areas. Her project involves undertaking field work, sample collection, treatment and characterization. Her research will require her to access the D&D mine sites, CGS laboratory facilities and analytical instruments. The Sustainable Resources and Environment Competency at CGS commit to support the study.

Dr Si Moja

Supervisor / Chief Scientist: Air Quality (CGS)

Date

10 Dec 2015

Acting Project manager: Mr. Khodani Matshusa

Sustainable Resources and Environment Competency

Date

10/12/2015

Recommended/Not Recommended

Approved/ Not Approved

Letter for access the site in clinics, hospitals and household yards for installation of single dust bucket unit



mineral resources
Department
Mineral Resources
REPUBLIC OF SOUTH AFRICA



Council for Geoscience

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Date: 17 November 2015

To whom it may concern

RE: REQUEST FOR PERMISSION TO INSTALL DUST MONITORING EQUIPMENTS AND TO COLLECT SURFACE AND TRAPPED DUST SAMPLES AROUND YOUR NEIGHBOURHOOD.

This serves to certify that the Department of Mineral Resources has tasked Council for Geosciences (CGS) (formerly known as Geological Survey of South Africa) to conduct a Derelict & Ownerless Mines Project ranking in respect of old and ownerless South African mines, with special emphasis on dust monitoring task and atmospheric dispersion modelling. The project is aimed at addressing nationwide environmental impacts from past mining activities.

The initial focus of the dust monitoring and atmospheric dispersion modeling task team involves sampling. This will lead to coming up with mitigation control measures for dust generating activities in the mines through wind blowing. The sampling programme in respect of the Mpumalanga, Limpopo and Northern Cape Provinces is planned to be conducted continuously.

You are therefore requested to give permission to CGS geoscientists to access old and ownerless mining sites and nearby residential areas for the above mentioned purpose.

Your cooperation in this regard will be highly appreciated. Current team is made of:

- ✓ Ms. Maphuti Kwata (Air Quality Officer: 012 841 1387; Cell: 076 678 9699; mkwata@geoscience.org.za)
- ✓ Mr Andries Masiya
- ✓ Ms Lerato Sebesho

Thanking you in advance.

Dr SJ Moja

Chief Scientist - Air Quality
Council for Geoscience;
Office: 012 841 8514; Cell: 082 082 5533
Email: sjmoja@geoscience.org.za

Synopsis

Soil and other geological materials found on the crust of the Earth are known to be rich in naturally occurring silicate minerals. Asbestos is one of the fibrous silicate minerals that was mined predominantly in some regions of “Limpopo, Mpumalanga and Northern Cape provinces in South Africa. Despite the cessation of asbestos mining due to associated human health effects in 2002, there is still a concern about possible environmental exposure to asbestos fibres. A single asbestos fibre is made of millions of microscopic needle-like fibrils which break easily to produce inhalable size fractions that are reported to cause lung diseases.

The main source of asbestos fibres in former mining areas is asbestos mine dumps and contaminated asbestos surface soil. Asbestos mine dumps in Limpopo Province are partially rehabilitated, while in Mpumalanga Province they are not rehabilitated and all these dumps are now under the care of government because the original owners have abandoned them. The settleable dust is the first indicator of airborne dust pollution and was used to select the sites to be monitored.

A pilot study was conducted to test the performance of the ASTM D1739:1998 and ASTM D 1739:1970 methods. In continuing with the study, an official ASTM D1739:1970 method was used and applied for the collection of settleable dust samples. A total ten (10) sites located around vulnerable human settlements that are in close proximity to the abandoned asbestos mine dumps were chosen in Mpumalanga and Limpopo Provinces respectively. Airborne, surface and trapped dust samples were collected once a month around human settlements that are in close proximity to the abandoned asbestos mine dumps from April 2016 to June 2017. Airborne dust samples were collected using the official settleable dust monitoring method, the E-sampler and the Air-Con 2 sampler. Surface dust was collected outdoors around the settleable dust collection units using a brush and dust pan and was stored in labeled zipper bags made of plastic material. Trapped dust samples were collected using sticky tape both indoors and outdoors around the window panes, on surfaces of furniture and on windscreens of old cars and were stored in labeled closed containers. Surface soil samples were also screened with the hand held asbestos analyser before collection.

The samples were extensively and carefully prepared and handled to avoid or minimize cross contamination using standard laboratory methods and were analysed using calibrated analytical instruments.

An adapted method was used to determine the presence of asbestos hazard in a form of mineral count. This method was also used for the identification of asbestos and other minerals in different dust samples using the XRD technique. Physical features of all minerals such as the shape, size and type were also determined as part of the characterization process using the SEM-EDS technique.

The ASTM D1739:1998 method gave rise to higher retention of settleable dust, hence it was found to be more efficient. Unfortunately, this best performing method is not legislated or regulated by the government. This researcher concludes that the reasons could be due to the different shapes of the windshield designs that may make it difficult to standardize and control. However, this information gap provides an opportunity of a longer focused study of this method with the intention of finding a standardized windshield design that could be recommended for use in the country.

Secondly, the units that had both water and algaecide gave rise to higher settleable dust in Mpumalanga. Three exceedances presented in decreasing order in Limpopo were 2724 mg/m²/day at Site E, 1638 mg/m²/day at Site D and 834 mg/m²/day at Site B in the same month of March 2017.

The XRF data of metal oxides, including these top three [Si(IV)O₂, Fe₂(III)O₃ and Al₂(III)O₃], confirm the dominance of silicate minerals in surface dust samples from both provinces. The XRD mineralogy data from filtered settleable dust show the dominance of the amphibole asbestos particulates ranging from 18 to 56 % in Limpopo province and 2.0 to 3.0 % in Mpumalanga province. Low presence of serpentine minerals with the highest being 2.0 % and 7.0 % in Limpopo and Mpumalanga provinces respectively. About 8.0 to 43 % of amphibole asbestos minerals were measured on trapped dust in Limpopo together with zero detection of serpentine.

No asbestos minerals were detected on trapped dust from Mpumalanga, despite the close proximity of the unrehabilitated asbestos mine dumps.

All airborne asbestos fibres that were captured on the filter substrates were above the limit value of 100 f/mL of air. The highest airborne asbestos fibre and concentration counts measured were 40 fibres and 2.083 f/mL concentration in October at Site A. The next highest fibre count concentration was measured in June with 6.590 f/mL at Site A and 5.272 f/mL at the Site D monitoring sites. In Mpumalanga the highest asbestos fibre concentration was 2.190 f/mL in June and 2.083 f/mL in November at the Site D. However, from the safety perspective all asbestos fibres or minerals inhaled are a hazard to human health. The study established that the adapted asbestos mineral count method succeeded in identifying and quantifying the asbestos minerals that existed in the settleable dust samples from the study areas. These outcome was successfully validated with the test undertaken using the officially recognized method of asbestos fibre count. The adapted mineral count method provides the research community with an alternative, cost effective and user-friendly method of analysis. Since the ASTM D1739:1998 method has been found to perform better than the officially recognized method, this study recommends that the regulators of air quality in the country consider it. But, the method will first require some improvement and standardization particularly the different wind shield designs before it could be officially accepted as the method of collection and analyses for settleable dust. It is hoped that the air quality research community will take up the challenge.

Keywords: Abandoned and ownerless, Settleable dust, Airborne dust, Surface dust, Trapped dust, Adapted asbestos mineral count, Asbestos fibre count, XRD, XRF, SEM-EDS, PCM, Limpopo Province, Mpumalanga Province.

Sinopsis

Grond en ander geologiese materiale wat op die aardkors aangetref word, is bekend dat hulle ryk is in silikaatminerale wat natuurlik voorkom. Asbes is een van die veselagtige silikaatminerale wat hoofsaaklik in sommige streke van die Limpopo, Mpumalanga en Noord-Kaap Provinsies in Suid-Afrika ontgin is. Ondanks die staking van asbesmynbou in 2002 as gevolg van gepaardgaande gesondheidseffekte op mense, is daar steeds kommer oor moontlike blootstelling aan asbesvesels in die omgewing. 'n Enkele asbesvesel bestaan uit miljoene mikroskopiese naaldagtige vesels wat maklik breek om partikels van inasembare grootte te produseer wat volgens berigte longsiektes veroorsaak.

Die belangrikste bron van asbesvesels in voormalige myngebiede is asbesmynhope en besmette asbesoppervlakgrond. Asbesmynhope in Limpopo Provinsie word gedeeltelik gerehabiliteer, terwyl hulle in Mpumalanga Provinsie nie gerehabiliteer word nie, en al hierdie mynhope is nou onder die regering se toesig omdat die oorspronklike eienaars die mynhope verlaat het. Die neerslagbare stof is die eerste aanduiding van stofbesoedeling in die lug en is gebruik om die terreine wat gemoniteer moet word, te kies.

'n Loodsstudie is uitgevoer om die prestasie van die ASTM D1739:1998 en ASTM D1739:1970 metodes te toets. In die loop van die studie is 'n amptelike ASTM D1739:1970 metode gebruik en toegepas vir die versameling van neerslagbare stofmonsters. In Mpumalanga en Limpopo Provinsies respektiewelik is daar altesaam tien (10) terreine gekies rondom kwesbare menslike nedersettings wat naby die verlate asbesmynhope geleë is. Stofmonsters in die lug, oppervlak en wat vasgevang is, is een keer per maand versamel vanaf April 2016 tot Junie 2017 rondom menslike nedersettings in die nabyheid van die verlate asbesmynhope. Stofmonsters in die lug is versamel volgens die amptelike neerslagbare stofmoniteringsmetode, die E monsternemer en die Air-Con 2 monsternemer. Oppervlakstof is buite met behulp van 'n kwas en stofpan rondom die neerslagbare stofopvangenhede opgevang en is in gemerkte ritsakke van plastiek materiaal geberg. Stofmonsters wat vasgevang is, is met behulp van kleeflint, binne en buite, om vensterruite, op meubeloppervlaktes en

op voorruitte van ou motors versamel, en is in gemerkte geslote houers geberg. Oppervlakgrondmonsters is ook voor versameling met die draagbare asbesanaliseerder gefilter.

Die monsters is breedvoerig en sorgvuldig voorberei en hanteer om kruisbesmetting tot 'n minimum te beperk deur gebruik te maak van standard laboratoriummetodes en is ontleed met behulp van gekalibreerde analitiese instrumente.

'n Aangepaste metode is gebruik om die teenwoordigheid van asbesgevaar in 'n vorm van mineraaltelling te bepaal. Hierdie metode is ook gebruik vir die identifisering van asbes en ander minerale in verskillende stofmonsters met behulp van die XRD tegniek. Die fisiese kenmerke van alle minerale soos die vorm, grootte en tipe is ook bepaal as deel van die karakteriseringsproses met behulp van die SEM-EDS tegniek.

Die ASTM D1739:1998 metode het gelei tot 'n hoër retensie van neerslagbare stof, en daarom is gevind dat dit doeltreffer is. Ongelukkig word hierdie metode wat die beste presteer nie deur die regering gewettig of gereguleer nie. Hierdie navorser kom tot die gevolgtrekking dat die redes kan wees as gevolg van die verskillende vorms van die voorruitontwerpe wat dit moeilik kan maak om dit te standaardiseer en te beheer. Hierdie inligtingsgaping bied egter 'n geleentheid tot 'n langer gefokusde studie van hierdie metode met die doel om 'n gestandaardiseerde voorruitontwerp te vind wat aanbeveel kan word vir gebruik in die land.

Tweedens het die eenhede wat beide water en alge-suurwater gehad het, gelei tot 'n hoër neerslagbare stof in Mpumalanga Provinsie. Drie oorskrydings wat in dalende volgorde in Limpopo aangebied is, was 2724 mg/m²/dag op perseel E, 1638 mg/m²/dag op perseel D en 834 mg/m²/dag op perseel B in dieselfde maand van Maart 2017.

Die XRF data van metaaloksiede, met inbegrip van hierdie top drie [Si(IV)O₂, Fe₂(III)O₃ en Al₂(III)O₃], bevestig die oorheersing van silikaatminerale in oppervlakstofmonsters van beide provinsies. Die XRD mineralogiedata van gefiltreerde, neerslagbare stof toon die oorheersing van die amfibool asbesdeeltjies wat wissel tussen 18 en 56 % in Limpopo Provinsie en 2.0 en 3.0 % in Mpumalanga Provinsie. Daar is 'n lae teenwoordigheid van serpentynminerale met die hoogste onderskeidelik 2.0 % en 7.0 % in die Limpopo en Mpumalanga Provinsies.

onderskeidelik. Ongeveer 8.0 tot 43 % van die amfibool asbesminerale is op vasgevangde stof in Limpopo gemeet, tesame met geen opsporing van serpentyn.

Geen asbesminerale is opgespoor in die vasgevangde stof van Mpumalanga nie, ondanks die nabyheid van die ongerehabiliteerde asbesmynhope.

Alle asbesvesels in die lug wat op die filtersubstrate vasgelê is, was bo die grenswaarde van 100 f/mL lug. Die hoogste asbesvesel en konsentrasietellings in die lug gemeet, was 40 vesels en 'n konsentrasie van 2.083 f/mL in Oktober op Terrein A. Die volgende hoogste veseltellingkonsentrasie is in Junie gemeet met 6.590 f/mL op die Terrein A en 5.272 f/mL op die Terrein D moniteringsterreine. In Mpumalanga was die hoogste asbesveselkonsentrasie 2.190 f/mL in Junie en 2.083 f/mL in November op Terrein D. Uit 'n veiligheidsperspektief is alle asbesvesels of minerale wat ingeasem word egter 'n gevaar vir die mens se gesondheid. Die studie het vasgestel dat die aangepaste asbesmineraaltellingmetode daarin geslaag het om die asbesminerale wat in die neerslagbare stofmonsters uit die studiegebiede bestaan te identifiseer en te kwantifiseer. Hierdie uitkoms is suksesvol bekragtig met die toets wat onderneem is met behulp van die amptelik erkende metode vir die telling van asbesvesel. Die aangepaste mineraaltellingmetode bied aan die navorsingsgemeenskap 'n alternatiewe, koste-effektiewe en gebruikersvriendelike ontledingsmetode.

Aangesien daar gevind is dat die ASTM D1739:1998 metode beter presteer as die amptelik erkende metode, beveel hierdie studie aan dat die reguleerders van luggehalte in die land dit oorweeg. Maar die metode sal eers verbetering en standaardisering verg, veral die verskillende windskermtwerpe voordat dit amptelik aanvaarkan word as die metode om neerslagbare stof te versamel en te ontleed. Daar word gehoop dat die gemeenskap wat luggehalte navors die uitdaging sal aanpak.

Sleutelwoorde: Verlate en eienaarlose, neerslagbare stof, stof in die lug, oppervlakstof, vasgevangde stof, aangepaste asbesmineraaltelling, asbesveseltelling, XRD, XRF, SEM-EDS, PCM, Limpopo Provinsie, Mpumalanga Provinsie.

Sengwalwakopana

Mabu le dišomišwa tše dingwe tša bothutaswika tše di hwetšagalago bokagodimo ba Lefase di tsebja di e na le diminerae tše dintši tša tlhago tše di diragalago ka tlhago. Marela ke e ngwe ya diminerae tše di nago le dimela tše di ntši kudu tše di bego di epšwa kudu mafelong a mangwe a diphrofentshe "diphrofentsheng tša Limpopo, Mpumalanga le North Cape Afrika Borwa. Le ge go feditšwe go epšwa marela ka lebaka la ditlamorago tše amanago le maphelo a batho ka 2002, go na le pelaelo malebana le go utullwa ga malwetši a *marela*. *Fibre* ke ye ngwe ya *marela* ye e dirilwego ka maekrosekopiki tše dimilione tše di ka senyegago bonolo go tšweletša khemobonolo yeo e hlamago malwetši a mafahla.

Sehlodikgolo sa malwetši a marela mafelong a mathomo ao go bego go le meepo ke sekoti sa *marela* le mabu a ka godimo ga *marela*. Dikoti tša meepo ya *Marela* Phrofentsheng ya Limpopo di mpšhafaditšwe ka tsela ye itšego, eupša Phrofentsheng ya Mpumalanga ga se tša mpšhafatšwa gomme mafelo a ka moka a laolwa ke mmušo gobane beng ba tšona ba di tlogetše. Lerole le ka rarollwago ke sešupopele sa tšhilafalo ya moya e dirwago ka moya gomme se be se šomišwa go kgetha mafelo ao a loketšwego go hlokomelwa.

Go ile gwa dirwa tekolo ya go leka tšhomo ya mekgwa ya ASTM D1739: 1998 le ASTM D 1739: 1970. Ge re ntšere tšwela pele ka thuto, go šomišitšwe mokgwa wa semmušo wa ASTM D1739: 1970 gomme wa šomišwa lebakeng la go kgoboketša sampole ya lerole e ka rarollwago. Mafelo a lesome (10) a hweditšwe kgauswi le bodulo ba batho bjo bo lego kotsing ka dikoti tša meepo ya *marela* di ile tša kgethwa diphrofentsheng tša Mpumalanga le Limpopo ka go latelana. Disampole tša moya tša ka godimo ga lefase, godimo le tše di khutilego di ile tša kgoboketšwa ga tee kgwedding kgauswi le bodulo ba batho tše di bego kgauswi kudu le dikoti tša meepo ya *marela* go tloga ka la 2016 Mopitlo go fihla ka Phupu 2017. Mehuta ya lerole ye sepetšwago ke moya e ile ya kgoboketšwa go šomišwa mokgwa wa semolao wa go tšweletša lerole, E-sampler le sampole ya Air-Con 2. Lerole la ka godimo le be le kgoboketšwa ka ntle go rarela dikarolo tša go kgoboketša lerole go šomišwa poratšhe le pane ya kota gomme

le bolokelwa ka mekotleng e nago le zipper ye dirilwego ka polasetiki. Sampole ya lerole le le bego le gaeletšwe le ile la kgoboketšwa ka theipi ya go momela bokagareng le bokantle bja morumofasetere, mabotong a phahlo, le godimo ga galasebokapele dikoloing tša kgale gomme tša bolokwa ka gare ga didirišwa tšeo di makilwego. Disampolo tša mabu a ka godimo di be di hlahlobjwa gape ka mokgwa wa go kgwa ka letsogo ke mohlalobi wa *marela* pele go kgoboketšwa.

Disampole di be di lokišitšwe kudu ebile di dirilwe ka tlhoko go efoga tšhilafalo ka mekgwa ye tlwaelegilwego ya laporatori gomme ba e hlahloba ba šomiša didirišwa tša go hlahloba.

Mokgwa o ikgethilego o šomišwa go hwetša bogona ba kotsi ya *marela* ka mokgwa wa palo ya diminerae. Mokgwa wo o be o šomišitšwe gape le go bošupong ba *marela* le diminerae tše dingwe ka gare ga disampole tše di fapanego tša lerole go šomišwa mokgwa wa XRD. Dibepegopono tša diminerae ka moka go swana le sebopego, bogolo le mohuta le tšona di be di tšewa e le karolo ya tshepetšo ya pharodipataka go šomišwa mokgwa wa SEM-EDS.

Mokgwa wa ASTM D1739: 1998 o ile wa dira gore go bolokwe lerole le phagameng ka go fetolegago, ka gona go hweditšwe gore le šoma gabotse kudu. Ka bomadimabe, mokgwa wo o tšweletši kudu ge o ngwadišwa ke molao go mmušo. Monyakišiši wo o phetha ka gore mabaka e ka ba ka lebaka la dibopego tše di fapaneng tša meralo ya setsi sa moya se se ka dirago gore go be boima go tseba le go laola. Le ge go le bjalo, sekgoba se sa tshedimošo se fa monyetla wa go ithuta nepišo e telele ya maikemišetšo a go hwetša moralo o tiišitšwego wa moya o ka šišinywago gore o šomišwe ka nageng.

Ya bobedi, diyuniti tše di bego di e na le meetsi le *algaecide* di ile tša tšweletša maemo a phagamego Mpumalanga Phrofentsheng. Ditekanyetšo tše tharo tše di tšweleditše ka tatelano ya taolo e fokotšegago e be e le 2724 mg/ m²/ letšatši go Site E, 1638 mg / m²/ letšatši go Site D le 834 mg/ m²/ letšatši go Site B kgwedding ye tee ya Hlakola 2017

Dintlha tša XRF tša di-oxide tša tšhipi, go akaretša tše tše tharo tša godimo [Si (IV) O₂, Fe₂ (III) O₃ le Al₂ (III) O₃], di tiša boleng bo phagameng ba diminerae tša silrate mehuteng ya lerole ye e tšwago diphrofentsheng ka bobedi. Dintlha tša XRD tša *mineralogy* tše di tšwago leroleng le tšhilafatšong di ka tšewa di bontšha phelo ya *marela* ya *amphibole* go tloga go 18 go iša go 56% phrofentsheng ya Limpopo le 2.0 go iša go 3.0% phrofentsheng ya Mpumalanga. Bogonatlasa ba diminerae tša *serpentine* tše phagameng ka go fetišiša e le 2.0% le 7.0% diphrofentsheng tša Limpopo le Mpumalanga ka go latelana. Go lekana 8.0 go iša go 43% ya diminerae tša *marela* tše lekantšwego di ile tša lekanywa leroleng le ageeletšwego ka Limpopo gammogo le go utullwa ga *serpentine*.

Ga go na diminerae tša *marela* tše di hweditšwego leroleng le ageeletšwego le tšwago Mpumalanga, le ge e le kgauswi kgauswi le dikoti tša mope wa maraba wa *marela* se a mpšhafatšwago.

Mehuta ka moka ya moya ya *marela* ye e bego e swerwe ka gare ga moya o bego o le ka godimo wa boleng ba moya wa 100 f /mL. Mohuta o phagamego go fetišiša wa moya wa *marela* le dipalo tša mahlorišo a lekantšwego e be e le tše 40 le bogolo ba 2.083 f /mL ka Diphallane go Site A. Tekanyomahloriš e latelago ya *fiber* e lekantšwe Phupu ka 6.590 f /mL go Site A le 5.272 f /mL Site D mafelong a tlhahlobo. Nageng ya Mpumalanga, di-*fibres* tša *marela* tše phagamego ka go fetišiša e be e le 2.190 f /mL ka Phupu le 2.083 f /mL ka Dibatsela go Site D. Le ge go le bjalo, go latela ponego ya tšhireletšo, *fibres* ka moka tša *marela* goba diminerae tše di hengwago di kotsi maphelong a botho. Boithuto bo bo utullotše gore mokgwa wo lekantšwego wa *marela* o bontšhitšwegošupo o atlegile go kgetholla le go hlakola diminerae tša *marela* tše di bego di le gona ka gare ga disampolo tša lerole le tšwago mafelong a boithuto. Sephetho se se netefaditšwe katlego le tlhahlobo ye e dirilwego e šomišwago mokgwa wo amogetšwego ke molao wa *marela fiber*. Mokgwa o lekantšwego wa diminerae o thuša setšhaba sa dinyakišišo ka mokgwa o mongwe wa tlhahlobo ye e šongwago, gabotse e bile ye botho.

Go tloga go mokgwa wa ASTM D1739: 1998 o hweditšwe o šoma gabotse go feta mokgwa wo amogetšwego ke molao, thuto ye e šupetša gore balaodi ba boleng ba moya nageng ba e nagane. Empa, mokgwa wo o tla hloka mpšhafatšo le maemo pele

kudu meralo ye fapaneng ya thebe ya moya pele e ka amogelwa ke molao e le mokgwa wa go kgoboketša le go sekaseka lerole le le ka rarolwago. Re tshepa gore setšhaba sa dinyakišišo tša boleng ba moya se tla tšea bothata bo.

Mantšu a bohlokwa: lahlilwego le hlokobeng, Lerolesesane, Lerole le le bego le moya, lerole le le ageeletšwego, Lerole la diminera le tša *marela*, palo ya dibjalo tša *Marela*, XRD, XRF, SEM-EDS, PCM, Phrofentsheng ya Limpopo, Phrofentsheng ya Mpumalanga.

Lingoloe tse ling

Mobu le lisebelisoa tse ling tsa jiloloji tse fumanehang bokaholimo ba Lefatše li tsejoa li na le liminerale tse ngata tsa tlhaho tse etsahalang ka tlhaho. Asbestos ke e 'ngoe ea liminerale tse nang le silika e ngata e neng e chekoa haholo libakeng tse ling tsa liprofinse tsa "liprofinse tsa Limpopo, Mpumalanga le North Cape Afrika Boroa. Leha ho felisoa morafo oa asbestos ka lebaka la litlamorao tse amanang le bophelo bo botle ba batho ka 2002, ho ntse ho na le ts'oenyeho mabapi le ho pepesetsoa ha tikoloho likhoele tsa asbestos. Fiber e le 'ngoe ea asbestos e entsoe ka likhoele tse limilione tse kang nale tse tsoang habonolo ho hlahisa likaroloana tse sa bonoeng tse tlalehang libaka-mafuamatšo.

Mohloli o ka sehloohong oa likhoele tsa asbestos libakeng tseo pele e neng e le tsa meepo ke lithako tsa asbestos le mobu o silafetseng oa asbestos. Likotlo tsa merafo ea Asbestos Profinseng ea Limpopo li nchafalitsoe ka tsela e itseng, athe Profinseng ea Mpumalanga ha e nchafatsoe 'me libaka tsena kaofela li laoloa ke mmuso hobane beng ba tsona ba ba lahlile. Lerōle le ka rarolloang ke letšoao la pele la tšilafalo ea moea e tsoang ka moea mme le ne le sebelisetsoa ho khetha libaka tseo li lokelang ho-shebelloa. Ho ile ha etsoa boithuto ba ho leka ts'ebetso ea mekhoha ea ASTM D1739: 1998 le ASTM D 1739: 1970. Ha re ntse re tsoela pele ka thuto, ho sebelisetsoe mokhoa oa semmuso oa ASTM D1739: 1970 'me oa sebelisoa bakeng sa ho bokella sampole ea lerōle e ka rarolloang. Sebaka sa libaka tse leshome (10) tse fumanehang haufi le bolulo ba batho ba tlokotsing tse haufi le libaka tse lahliloeng tsa meepo ea asbestos li ile tsa khethoa liprofinse tsa Mpumalanga le Limpopo ka ho latellana. Lisampole tsa moea tse ka holim'a lefatše, holimo le tse patiloeng li ile tsa bokelloa hang ka khoeli ho potoloha libaka tsa bolulo tsa batho tse haufi haholo le libaka tse lahliloeng tsa moepo oa asbestos ho tloha ka Mmesa 2016 ho fihlela ka Phuptjane 2017. Mefuta ea lerōle e tsamaisoang ke moea e ile ea bokelloa ho sebelisoa mokhoa oa semolao oa ho hlahisa lerōle, E-sampler le sampole ea Air-Con 2. Lerōle le kaholimo le ne le bokelloa ka ntle ho potoloha likarolo tsa ho bokella lerōle le sebelisa brashi le pane ea patsi mme le bolokiloe ka mekotleng e nang le zipper e entsoeng ka thepa ea polasetiki. Mehlala ea lerōle e neng e tsoasehile e ile ea bokelloa ho sebelisoa theipi e khangoang ka tlung le kantle kahare ho lifensetere, ka holim'a thepa ea ka tlung le lifensetereng tsa likoloi tsa khale 'me li bolokiloe ka har'a

lisebelisoa tse koetsoeng. Meetso ea mobu e kaholimo le eona e ile ea hlahlojoa ka letsoho le ts'oaroang ka asbestos pele ho pokello. Mehlala e ne e hlophisitsoe haholo ebile e entsoe ka hloko ho qoba ho silafatsa kapa ho fokotsa tšilafalo ea tšebeliso ea mekhoa e tloaelehileng ea laboratori mme e ile ea hlahlojoa ho sebelisoa lisebelisoa tsa tekanyetso.

Mokhoa o ikhethileng o sebelisitsoe ho fumana ho ba teng ha kotsi ea asbestos ka mokhoa oa palo ea liminerale. Mokhoa ona o ne o boetse o sebelisoa bakeng sa ho khetholla asbestos le liminerale tse ling ka har'a disampole tse fapaneng tsa lerōle ho sebelisoa mokhoa oa XRD. Litšobotsi tsa 'mele tsa liminerale tsohle tse kang sebopeho, boholo le mofuta le tsona li ne li nkuoa e le karolo ea ts'ebetso ea sebopeho ho sebelisa mokhoa oa SEM-EDS. Mokhoa oa ASTM D1739: 1998 o ile oa etsa hore ho bolokoe lerōle le phahameng ka ho fetelletsa, ka hona ho fumanoa hore le sebetsa hantle haholo. Ka bomalimabe, mokhoa ona o atlehileng ka ho fetisisa ha o ngolisoe ke molao kapa 'muso. Mofuputsi enoa o phethela ka hore mabaka a ka ba teng ka lebaka la sebopeho se fapaneng sa meralo ea setsi sa moea se ka etsang hore ho be thata ho tseba le ho laola. Leha ho le joalo, lekhalo lena la tlhaiso-leseling le fana ka monyetla oa ho ithuta ho tsepameng molemong oa mokhoa ona ka sepheo sa ho fumana moralo o tiisitsoeng oa moea o ka kothalletsoang hore o sebelisoe ka har'a naha.

Ya bobedi, diyuniti tse neng di na le metsi le algaecide li ile tsa hlahisa maemo a phahameng a ho tsetsahala Mpumalanga. Litekanyetso tse tharo tse fanoeng ka tatellano ea taolo e fokotsehang e ne e le 2724 mg/m²/letsatsi ho Site E, 1638 mg/m²/letsatsi ho Site D le 834 mg/m²/letsatsi ho Site B ka khoeli e tšoanang ea Hlakubele 2017.

Lintlha tsa XRF tsa li-oxide tsa tšepe, ho kenyelletsa tsena tse tharo tse holimo [Si (IV) O₂, Fe₂ (III) O₃ le Al₂ (III) O₃], li tiisa boleng bo phahameng ba liminerale tsa silicate mefuteng ea lerōle e tsoang liprofinseng ka bobeli. Lintlha tsa XRD tsa mineralogy tse tsoang lerōleng le ts'ilafatsoang li ka nkuoa li bonts'a phello ea asbestos ea amphibole ho tloha ho 18 ho isa ho 56% profinseng ea Limpopo le 2.0 ho isa ho 3.0% profinseng ea Mpumalanga. Boteng bo tlase ba liminerale tsa linoha tse phahameng ka ho fetisisa e le 2.0% le 7.0% liprofinseng tsa Limpopo le Mpumalanga ka ho latellana. Hoo e ka

bang 8.0 ho isa ho 43% ea liminerale tsa asbestos tse lekantsoeng li ile tsa lekanngoa lerōleng le ts'oaroang ho la Limpopo hammoho le ho sibolloa ha noha. Ha ho na liminerale tsa asbestos tse fumanoeng lerōleng le tsubelletsoeng le tsoang Mpumalanga, leha ho le haufi le marang-rang a litopo tsa asbestos tse sa ntlafatsoang.

Mefuta eohle ea moea e kang asbestos e neng e hapiloe kahare ho moea o ne o le kaholimo ho boleng ba moea oa 100 f /mL. Mofuta o phahameng ka ho fetisisa oa moea oa asbestos le lipalo tsa mahloriso tse lekantsoeng e ne e le likhoele tse 40 le boholo ba 2.083 f /mL ka Mphalane ho Site A. Khakanyo e latelang ea fiber fiber e latelang e lekantsoe ka Pherekhong ka 6.590 f /mL ho Site A le 5.272 f /mL setsing D libaka tsa tlhahlobo. Naheng ea Mpumalanga, li-fiber tsa asbestos tse phahameng ka ho fetisisa e ne e le 2.190 f /mL ka Phuptjane le 2.083 f /mL ka Pulungoana ho Site D. Leha ho le joalo, ho latela pono ea ts'ireletso, likhoele tsohle tsa asbestos kapa liminerale tse kentsoeng li kotsi bophelong ba motho. Boithuto bo fumane hore mokhoa o lekantsoeng oa "asbestos" o ntlafalitsoeng o atlehile ho tseba le ho hlakisa liminerale tsa asbestos tse neng li le teng ka har'a mehlala ea lerōle e tsoang libakeng tsa boithuto. Sephetho sena se netefalitsoe ka katleho le tlhahlobo e entsoeng e sebelisang mokhoa o amohetsoeng ka molao oa asbestos fiber count. Mokhoa o lekantsoeng oa liminerale o thusa sechaba sa lipatlisiso ka mokhoa o mong oa tlhahlobo o sebetsang, o sebetsang hantle ebile o sebelisang botsoalle. Ho tloha ha mokhoa oa ASTM D1739: 1998 o fumanoa o sebetsa hantle ho feta mokhoa o amohetsoeng ka molao, thuto ena e khothaletsa hore batsamaisi ba boleng ba moea naheng ba e nahane. Empa, mokhoa ona o tla hloka ntlafatso le maemo pele haholo mealo e fapaneng ea thebe ea moea pele e ka amoheloa ka molao e le mokhoa oa ho bokella le ho sekaseka lerōle le ka rarolloang. Re tšepa hore sechaba sa lipatlisiso tsa boleng ba moea se tla nka bothata bona.

Mantsoe a bohlokoa: U lahliloe khrehloa ebile ha u na thepa, U na le lerōle le tsitsitseng, Lerōle le nang le moea, lerōle le tsubelletsoeng, palo ea liminerale tsa asbestos, palo ea li-asbestos, XRD, XRF, SEM-EDS, PCM, profinseng ea Limpopo, profiseng ea Mpumalanga.